THE RUGBY RADIO STATION OF THE BRITISH POST OFFICE.

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Summary.

This paper gives a general description of the Post Office high-power radio station erected at Hillmorton near Rugby. The introduction sets out the requirements which the design had to meet.

The paper is divided broadly into three Sections :—Power Plant, High-frequency Generating Valve Plant, and Masts and Aerials.

The first Section deals with the selection and type of power plant employed for converting the e.h.t. alternating-current supply to suitable e.h.t. direct-current and l.t. direct-current and l.t. alternating-current supplies for use on the various parts of the installation, and the precautions necessary in dealing with a wireless load of the magnitude involved. The method of providing lighting for the masts for warning aircraft of obstruction is given.

The high-frequency generating-valve plant Section deals with the design of valve generating plant suitable for full-power transmission or subdivision into two transmitters for use with larger and smaller portions of the whole aerial, and gives the methods adopted for maintaining constant frequency, successive amplification and freedom from harmonics. This Section includes :—The e.h.t. direct-current supply ; the general scheme of circuits ; the filament supply ; the excitation unit ; consideration in regard to the size of power unit ; the power unit ; the paralleling of valves in a power unit ; the paralleling of power units ; safety devices and control circuit ; the control table ; types of coupled circuits ; the design of inductances for high power ; relative positions of amplifiers and aerial circuit ; method of keying and shape of signal.

The masts and aerial Section includes :—A brief general description of the 820-ft. masts ; the method of insulating the masts and the stays ; the method of staying the masts ; tensions on the stays, etc. ; the method of applying test load to top of masts ; the aerial system ; aerial insulation ; aerial spreaders ; earth system ; curves of aerial resistance ; voltage on aerial, etc.

The final Section gives the general results obtained to date, and a brief description of the experimental telephony installation.

Introduction.

When the Government decided upon the provision in England of a wireless station with a world-wide range, the Post Office Engineering Department was entrusted with the task of its erection. The Wireless Telegraphy Commission which was originally appointed under the chairmanship of the late Lord Milner with Dr. W. H. Eccles (Vice-chairman), Mr. E. H. Shaughnessy and Mr. L. B. Turner as members, undertook the general design of the station. The Post Office engineers in consultation with the Wireless Telegraphy Commission carried out considerable preliminary experimental work and prepared detailed drawings and designs for the station equipment as a whole and for most of the plant ; they also prepared the detailed specifications to which manufacturers have designed or made the remainder of the plant.

In the preliminary design of the station it was considered that in order to ensure reliable communication when working on a wave-length of about 18 000 m (16·66 kilocycles) a minimum working current of 500 amperes in an efficient aerial supported on 820-ft. masts would be required. To meet this requirement and provide a safe working margin it was decided that the high-frequency generating valve plant should be capable of dealing with an input of 1 000 kW to provide for a possible necessary low working efficiency of 50 per cent. Such an installation would produce an aerial current of about 700 amperes to meet bad atmospheric conditions.

Originally it was considered that sixteen 820-ft. masts would be required to support a suitable aerial, but to avoid any unnecessary expenditure it was decided to erect in the first instance an aerial having a designed capacity of 0·045 μF on 12 insulated 820-ft. masts and to carry out tests to ascertain the limitations imposed on the aerial power obtainable by such factors as corona, insulation, etc., and to obtain data as regards the range of the station using this maximum power.

In order to keep this description of the Rugby radio station within reasonable limits it is proposed to describe the power plant and the external plant briefly and the radio-telegraph plant in detail.

Site.

Owing to the large area required, considerable difficulty was experienced in obtaining a site, but ultimately an area of 900 acres (about 1½ miles long by 1 mile wide) bounded on the east side by Watling-street and on the west side by the Oxford canal was obtained at Hillmorton about 4 miles south-east of Rugby. The ground is level and not surrounded by hilly or wooded country, although a fox covert on the site had to be demolished, as it was under the proposed aerial. A water supply is available from a stream running through the site; the nearby railways and the Oxford canal afford transport facilities. The station buildings are erected about the middle of the site (see Fig. 1).

Power Plant.

The question of the power supply for the station was one which was very carefully considered and, after a close examination of conditions on the basis of comparative costs and reliability, it was decided to accept a bulk supply from the Leicestershire and Warwickshire Electric Power Co., who are the authorized suppliers in the area.

The company has generating stations at Warwick and

Hinckley, the Rugby area being served by duplicate mains from Warwick, whilst arrangements for linking with Hinckley are in contemplation. The incoming supply is three-phase, 50-cycle alternating current, having an earthed neutral and 12 000 volts between phases.

Duplicate underground cables are provided between the radio station and the company's substation at Rugby, where automatic regulators are installed.

The two feeder cables terminate at the radio station in a separate selector switch cubicle which permits of either or both cables being connected to the e.h.t. alternating-current switchboard.

The radio-station power house consists primarily of a machine room 185 ft. by 47 ft. spanned by an 11-ton overhead travelling crane. The general layout is shown in Fig. 2. One end of the room is partitioned off for workshop and stores to which the crane has access and which can be readily utilized for extensions if this becomes necessary. Parallel with the main room is an annex, the lower portion of which contains a battery room and six trans-

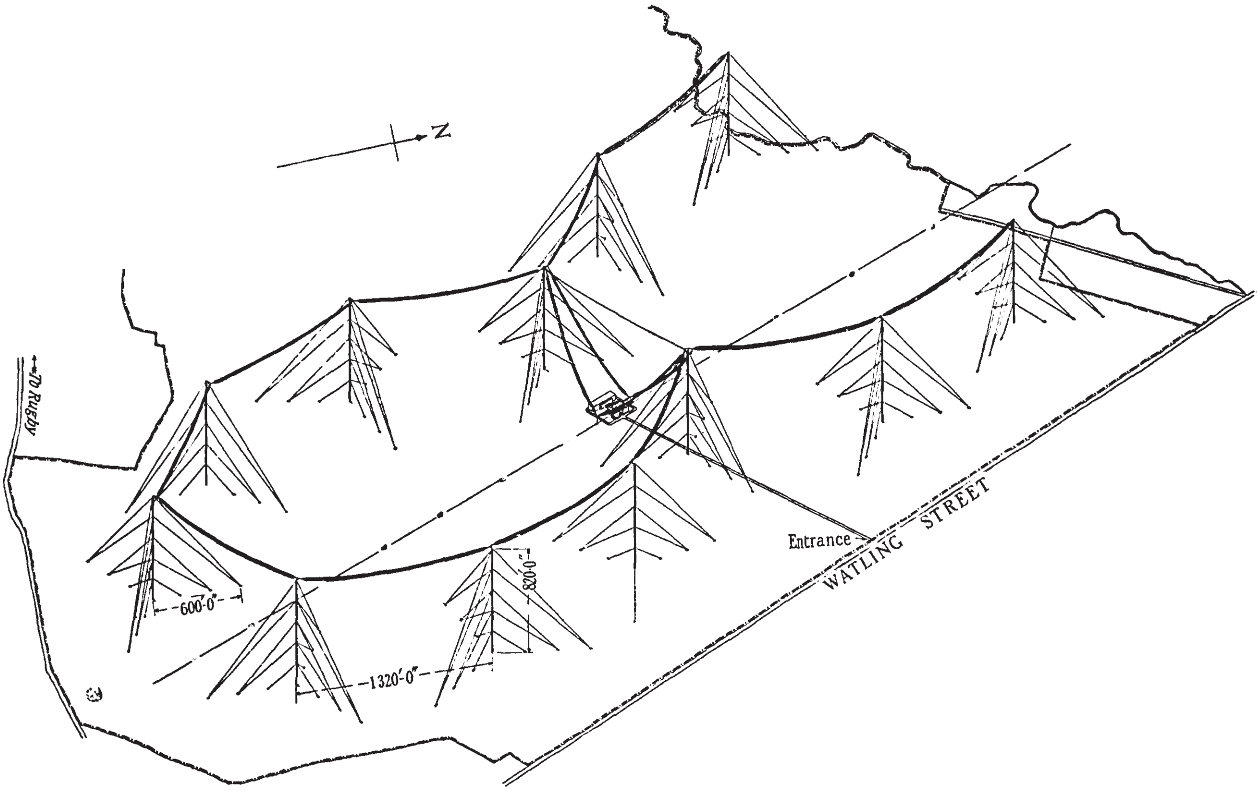

Fig. 1.—Isometric view of station.

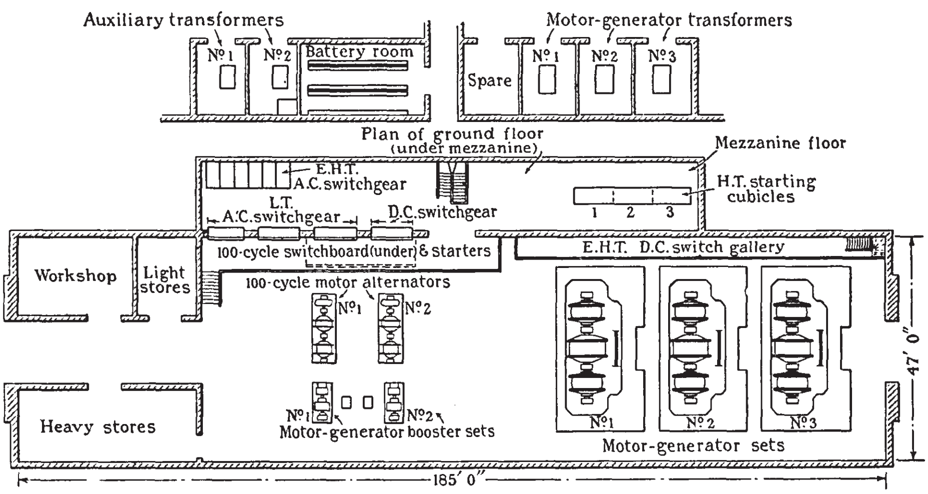

Fig. 2.—Plan of power house (scale $\frac{1}{40}$ in. = 1 foot).

former rooms. A separate room is provided for each power transformer and these rooms can only be entered from outside the building. They are closed by steel doors furnished with ventilating louvres. The upper floor of the annex is a switch gallery open to the machine

valves, two frequency-converter sets used for heating valve filaments, together with motor starting cubicles and alternator control panels, and lastly two motor-generator and booster sets for battery charging and low-tension d.c. supply.

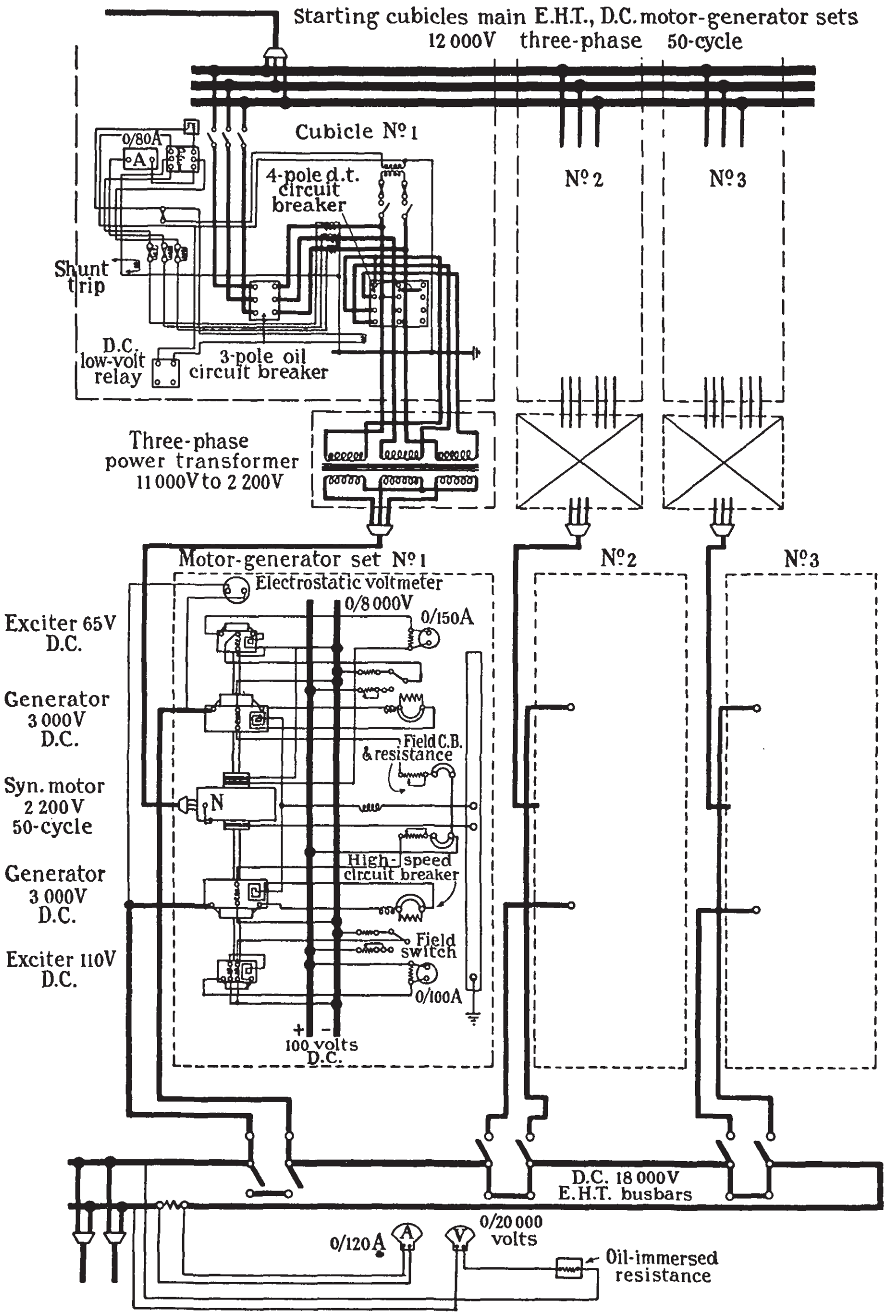

FIG. 3.—Wiring diagram of motor-generator sets.

room. This gallery contains the high- and low-tension a.c. switchboards, high-tension a.c. starting cubicles for the main generators and low-tension d.c. switchboard.

In the machine room are the main motor-generator sets for providing high-tension direct current to the

All power used, other than that required for the main motor-generators, is supplied by two auxiliary step-down (12 000/416 volt) transformers of 450 kVA output through the main low-tension a.c. switchboard. For reasons explained later it was found more convenient to supply

each main motor-generator set through a separate transformer.

The larger motors (i.e. over 100 kW) installed are synchronous machines capable of operating on 0·9 leading power factor, and as a result the station can be operated on unity power factor.

The e.h.t. a.c. switchboard is a 6-panel board consisting of 5 truck cubicles and a metering cubicle. The first truck contains an oil switch controlling the supply to busbars and also contains the company's meters with their respective instrument transformers. The next panel consists of a cubicle containing the Department's check meters and potential transformer.

The four remaining panels are feeder truck cubicles, two being connected to the auxiliary 450-kVA transformers situated immediately below the switchboard, whilst the third, of 2 000 kW capacity, controls the supply to the main motor-generator sets. The fourth truck is at present spare and interchangeable with the remaining three feeder trucks. The low-tension a.c. 416-volt switchboard is of the normal slate pattern containing 16 panels, and controls all auxiliary power inside the station and the outside feeders to mast winches, pumps, etc. These switchboards, together with a number of other switchboards and cabling, were supplied and erected by the General Electric Co., Ltd.

The requirements of the valve transmitter set called for a supply of d.c. power of from 1 000 to 1 500 kW at a potential of from 10 000 to 18 000 volts, with the negative side at earth potential, the higher voltage being provided to cope with probable developments in transmitting valves in the near future.

Owing to the possible failure of valves it was essential that whatever type of plant was installed it would have to be capable of standing a dead short-circuit with impunity. Other special requirements were ability to operate under rapidly fluctuating loads, low self-inductance, and absence of voltage ripple.

The relative merits and suitability of machines, mercury-arc rectifiers and thermionic valve rectifiers for this duty were considered. Tenders were invited for the various types and it was finally decided to install motor-generator sets (see also Report of Wireless Telegraphy Commission, Command Paper 1572–1922).

The machines were manufactured by the British Thomson-Houston Co., Ltd., of Rugby and are an interesting development from machines designed for high-tension d.c. traction work. The Rugby generators, owing to the higher voltage and their operation in series, possess several new features, some particulars of which have already appeared in the technical Press and will only be briefly referred to here. Fig. 3 shows a wiring diagram of these sets. Three sets are provided, each having an output of 500 kW at 6 000 volts d.c., and space is provided for the accommodation of a fourth set. Each set consists of a three-phase self-starting synchronous motor of 640 kVA wound for 2 200 volts between phases, rigidly coupled to two d.c. generators connected in series, and two exciters, one of which is the main exciter and the other the motor field exciter; the main exciter provides field current for both d.c. generators and for the field of the motor exciter.

Each d.c. generator is a bipolar machine having an output of 250 kW at 3 000 volts and provided with interpoles and compensating winding. The magnet frames of cast steel are split diametrically and in order to avoid awkward joints in the pole-face windings the break has been arranged through the centre of the main poles which consist of twin poles, each half carrying its own spool. Another unique feature of the magnetic circuit is a band of laminations incorporated in the yoke to provide an undamped path for the commutating flux under rapidly varying loads. The commutator is of the same diameter as the armature, and all metallic parts in the vicinity of the commutator which are connected to the frame are protected by insulating shields. A series of fan blades mounted between the armature and commutator provide a blast of air across the commutator. The brush gear is completely encased in bronze boxes, the connections to which produce magnetic fields directed to blow out from the machine any arc which may be formed at the brushes.

The bearings are each provided with a thermal relay which, in the event of overheating, rings a bell on the control panel and lights an indicating lamp on the hot bearing.

In order to avoid the use of insulated couplings between motor and generators, each set is supplied with power through a separate transformer. These transformers, manufactured by Messrs. Johnson and Phillips, are wound for 12 000 volts on the primary side and 2 200 volts on the secondary side. The insulation of the secondary winding from the primary winding and core bunched was designed for and subjected to a flash test of 50 000 volts. The secondary side is connected directly to the motor terminals by means of a 3-core paper-insulated cable, and all a.c. switchgear is on the primary side of the transformer.

The d.c. controls of each set are mounted on an auxiliary baseplate which carries generator field rheostats and shunt field rheostats for the main exciter and motor exciter.

The main baseplate of each set and the auxiliary baseplate are insulated from earth by being mounted on groups of porcelain insulators. The neutral point of the motor stator is connected to the baseplate. The mid-point between the d.c. generators is also connected to the base-plate through a leakage relay. In this way the potential of any portion of the set relative to the frames is limited to 3 000 volts d.c.

When working in series each set has a baseplate potential corresponding to its position in the circuit; thus the first baseplate will be at 3 000 volts, the second at 9 000 volts and the third at 15 000 volts above earth in each case.

The wiring diagram of the control panels on the auxiliary baseplate is shown in Fig. 4.

Each main baseplate carries two high-speed circuit breakers each connected in series with a generator armature. The high-speed circuit breaker is set for instantaneous tripping on about 5 times full-load current; it inserts a blocking resistance in circuit and at the same time, by means of auxiliary contacts, trips the generator field contactor. The action of the circuit breaker is extremely rapid, the contacts being fully opened within 0·02 sec., whilst in order to suppress the

generator fields as rapidly as possible the field contactors open the circuit without inserting discharge resistances. Each set is completely surrounded by an earthed metallic screen, and the foundations contain a metallic network which is connected to the earthed screens. All controls are operated by means of insulated spindles from a position outside the screens. The e.h.t. d.c. terminals of each set are connected to a 2-position selector switch mounted on a gallery carrying the busbars. In one position the switch connects the machine in series with the busbars, whilst in the other position the machine is isolated and the gap in the busbars bridged. The screened enclosures and busbar gallery are protected by gates having double electrical interlocks. In addition, it is impossible to enter the machine enclosures without first earthing the baseplate, thus preventing any possi-

delta oil switches, overload and low-voltage trips, ammeter and power-factor meter with current and potential transformers. Each cubicle is located on the switch gallery immediately over its associated transformer, to which it is connected by bare conductors passing through porcelain bushings in the floor. In operation the main oil switch connects one end of the three primary windings of the transformer to the line. The second oil switch is of the 4-pole double-throw type with double escutcheon. On closing the starting-throw the inner ends of the primary windings are connected together, the transformer thus being star-connected to the line and delivering 1 270 volts between phases to the motor. The operation of a sliding interlock bar trips the starting-throw and frees the running-throw which can then be closed to connect the transformer

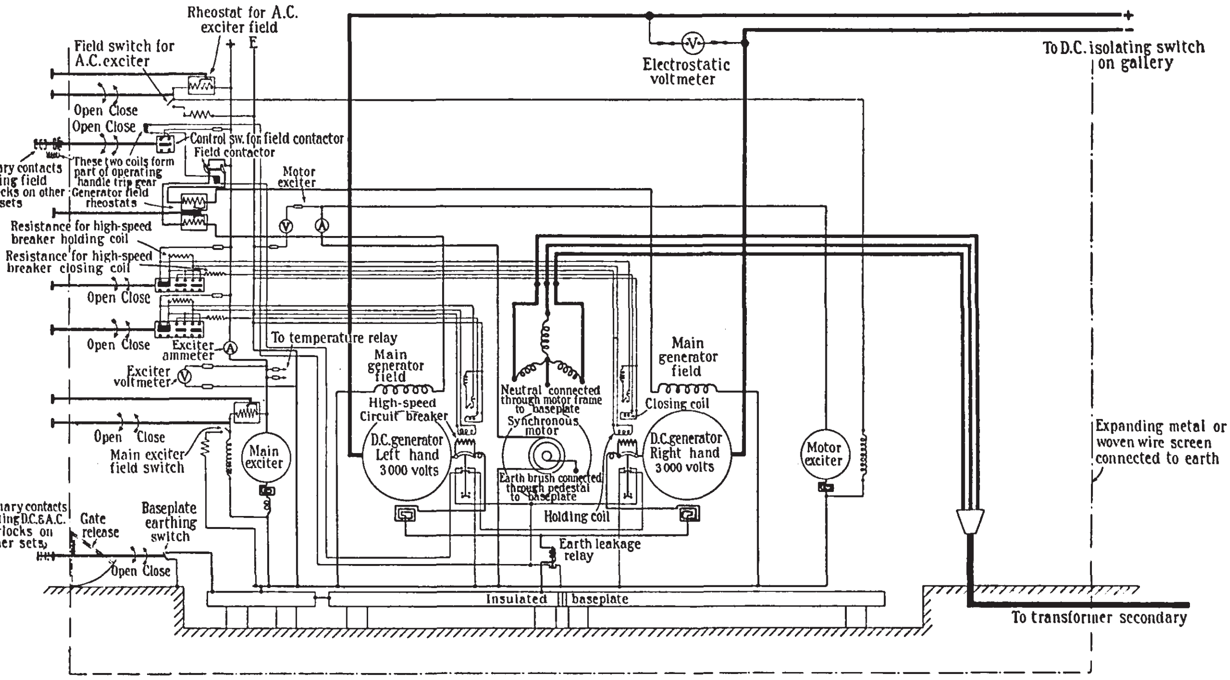

FIG. 4.—Wiring diagram of control panel of 500-kW motor-generator set.

bility of shock from a static charge left on a machine after closing down. A complete system of electrical interlocks external to the machine enclosures is associated with the selector switches, machine controls and a.c. starters. The supply for this interlock system is taken from the 240-volt d.c. battery supply, and no-volt devices are provided to shut down the plant in the event of this supply failing. Any attempt to enter a live enclosure or to operate a selector switch while the busbars are excited will trip the field controls of all running machines. In the event of any generator developing a fault, or in the event of any high-speed circuit breaker opening on overload, means are provided to trip the field controls of all other generators connected to the busbars. As previously mentioned, the motor starting gear for each set is on the 12 000-volt side of the step-down transformer and consists of a steel cubicle containing isolating links, main and star-

primary in delta, giving a normal running voltage of 2 200 volts between phases on the secondary. The switch cubicles were supplied by the British Thomson-Houston Co., Ltd.

In spite of the large dimensions of the machines for their output, necessitated by voltage requirements, the test-results showed an overall efficiency of over 87 per cent.

In addition to the ordinary tests, the machines were subjected to short-circuit tests while fully excited; in the case of one set this test was repeated 20 times, in all cases without flash-over or damage of any kind. A copy of oscillograms taken on a single set by the B.T.H. Co. during the official test is shown in Fig. 5. After installation two short-circuit tests were carried out with all sets in series and fully excited to a total of 18 000 volts d.c. with equally satisfactory results.

The d.c. supply from the busbars is transmitted to the

valve room through duplicate armoured concentric paper-insulated cables, the inner conductor in each case being the high-tension conductor, whilst the outer conductor carries the return current at approximately earth potential. The cables terminate in a steel cubicle

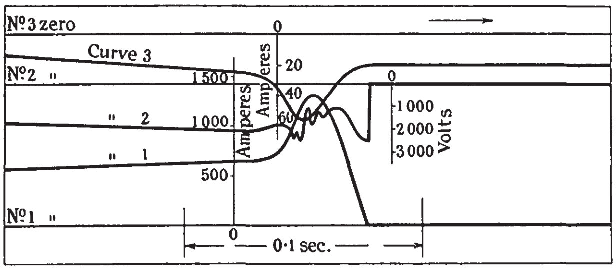

FIG. 5.—Oscillogram of short-circuiting test on 500-kW, 6 000-volt motor-generator set.

Curve 1.—Short-circuit current (1 cm = 756 amps.).
Curve 2.—Voltage across high-speed circuit breaker, commutating pole and compensating windings (1 cm = 3 271·8 volts).
Curve 3.—Shunt field current (1 cm = 48 amps.).

switchboard (Fig. 6) supplied by the General Electric Co., Ltd., consisting of two cubicles each provided with isolator and earthing switches, electrostatic voltmeter, and an electrically operated single-pole 18 000-volt d.c. oil circuit-breaker provided with overload and no-volt trips. The no-volt trip coil on this switch forms part of a low-tension d.c. circuit and will be referred to subsequently as the "holding coil." One cable terminates in each cubicle, one cubicle being used to supply the main telegraph transmitter, and the other cubicle serving the experimental telephone transmitter. In addition the telegraph cubicle has a selector switch

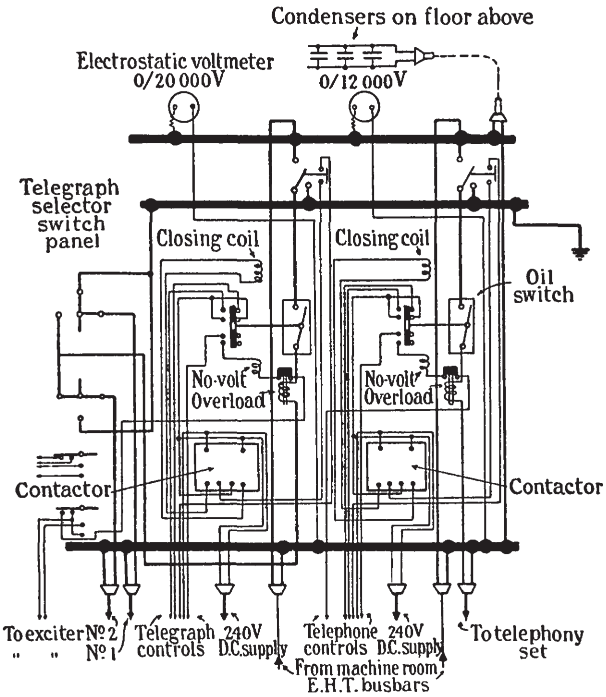

FIG. 6.—Wiring diagram of e.h.t. direct-current cubicles in valve room.

interlocked with the oil switch which connects the e.h.t. d.c. supply to one of two short alternative feeders to the telegraph transmitter, the unused feeder being earthed. The oil circuit-breaker is designed to trip rapidly on interruption of the "holding coil" circuit which is energized from the 240-volt d.c. supply, and during tests the contacts opened 0·18 sec. after interruption of the "holding coil" circuit.

The use of oil circuit-breakers to rupture high-tension d.c. circuits is thought to be a novelty, but tests on short-circuits of 18 000 volts showed that the switch could successfully clear the fault without damage.

The valve filament supply of the station is obtained from two 200-kVA frequency-converter sets each consisting of a 416-volt 50-cycle synchronous motor driving a 200-kVA 354/478-volt 100-cycle three-phase alternator. Each set is provided with a pony motor and exciter. Tirrill regulators are provided on each alternator control panel to limit a.c. voltage fluctuations, and as an additional safeguard the regulators are fitted with excess-voltage cut-outs to provide against the possible failure of the regulator. The voltage maintained by the Tirrill regulators can be varied by remote control from the valve room.

These sets, together with the smaller d.c. generator and other motor-generator sets installed elsewhere and referred to later, were provided by Messrs. Newton Brothers, Derby. The alternator control panels were provided and erected by the General Electric Co., Ltd.

For the operation of various control and protective circuits, and as an emergency lighting supply, a small secondary battery consisting of 120 cells of 200 ampere-hours' capacity has been installed. For charging this battery, 30-kW induction-motor-driven generator and booster sets are provided in duplicate.. Automatic switches are provided to short-circuit and disconnect the booster, leaving the battery on the busbars in the event of the motor stopping, the generators being protected by overload and reverse-current circuit breakers. The d.c. busbar voltage is kept at 240 volts and the booster supplies the difference between the battery voltage and this value.

The workshop situated at one end of the power house is provided with a work bench and a number of power-driven machine tools including a 6-in. screw-cutting lathe, 21 in. vertical drilling machine, power hacksaw and shaping machine.

All circuits and machines are provided with protective devices designed to prevent damage from high-frequency currents. On the e.h.t. direct-current generator set, spark-gaps having non-inductive resistances in series are connected across each generator armature. On other machines or feeders straight-filament lamps in cast-iron boxes are shunted across the machine terminals or feeder. In a few cases where the machine current is small a condenser of 2 μF capacity with lamps in series is used.

The switchgear in the valve room consists of the steel cubicles for controlling the e.h.t. direct-current supply and a dead-front board of 20 slate panels carrying all auxiliary supplies for the telegraph transmitter, together with some of the supplies for the telephone sets. A small dead-front slate board of 4 panels supplies all other power required for the experimental telephone set.

The 20-panel board controls the supplies for filaments, grids and anodes of the earlier valve stages and for grid bias of the main valves. The supplies are obtained from duplicate motor-generator sets housed in a small machine room adjoining the valve room.

Other supplies provided by this board are a 240-volt d.c. supply for switch controls and machine excitation, a 50-cycle 416-volt three-phase supply to motors of motor-generator sets and air compressors for keys, a 300-volt d.c. supply for the grid bias of the experimental telephone transmitter, and lastly the 354/478 three-phase 100-cycle supply for heating valve filaments on the telegraph and experimental telephone sets.

Two sets of busbars are provided for the filament supply, one set being associated with each alternator, to which it is connected through a remote-controlled solenoid-operated oil switch. The filament supply to individual valve panels of the telegraph set is taken through a double-throw 3-pole switch on the front of the board and then through a 3-pole contactor mounted behind the board. The double-throw switch enables the valve panel to be connected to either set of busbars, whilst the contactor is in each case remote-controlled from the valve panel where a step-down transformer is situated.

The switchboard and contactors were supplied by the General Electric Co., Ltd.

While on the subject of power supply it may be interesting to mention that a supply of current was required for providing aircraft obstruction lights on certain masts. As the masts are highly insulated from earth it was impracticable to take supply directly from the mains. The difficulty was overcome by mounting a 2-kW 240-volt d.c. dynamo on the mast and driving it by means of a suitable 50-cycle squirrel-cage motor on the ground through the medium of a rubber motor-cycle belt. The motor, which is a totally enclosed weatherproof machine, is provided with automatic starter actuated by a Venner time switch so that the lights are automatically switched on at sunset each evening and switched out at dawn.

High-Frequency Generating Valve Plant.

The high-frequency generating plant was designed to utilize thermionic valves and to be capable of dealing, if necessary, with an output to the aerial of 500 kW continuously under commercial conditions. For the purpose of preliminary calculations the wave-length was taken as 18 000 m, the capacity of the aerial as $0 \cdot 045\ \mu$F, and the total aerial circuit resistance as 1 ohm.

The aerial was designed so that it could be used as one large aerial or be readily divided at the station building into two unequal parts to provide for simultaneous telegraph transmissions on two aerials, and for this purpose two separate down-leads were provided.

The high-frequency generating plant had therefore to be so designed that it could be readily used for such simultaneous transmissions when necessary. However, after the plans had been prepared it was decided to carry out experiments in transatlantic telephony from Rugby in association with the American Telephone and Telegraph Co., and the smaller part of the aerial has been reserved for this purpose for the present and so diverted from its intended function of forming part of a large aerial for the full telegraphic power of the station, or of being used for a second radio-telegraphic channel.

In consequence, the aerial immediately available for the telegraph transmitter is the larger part erected on 8 masts which has a capacity of $0 \cdot 033\ \mu$F. The resistance, as measured after erection, of this aerial at various frequencies in the region of the required transmitting frequency with the masts insulated, is given by curve A of Fig. 7. Curve B of the same figure gives the total resistance of aerial and aerial tuning inductance.

It is essential with the ever-increasing number of transmitting stations that special efforts should be made to maintain constant the frequency of a radio transmitting station and thus reduce the possible interference to a minimum by permitting the use of highly selective receivers.

It was therefore decided to investigate and, if possible, develop the use of the valve-maintained tuning-fork of Eccles and Jordan as a primary source of constant oscillations. The Post Office research staff produced a suitable combination which was tried out commercially at the Post Office Northolt valve station and proved successful.* The primary source or master oscillator at Rugby is a valve-maintained tuning-fork having a frequency of about 1 800 cycles per second (this frequency being adjustable within small limits), and the high frequency required for controlling the main set is obtained by selecting the 9th harmonic of the tuning-fork frequency.

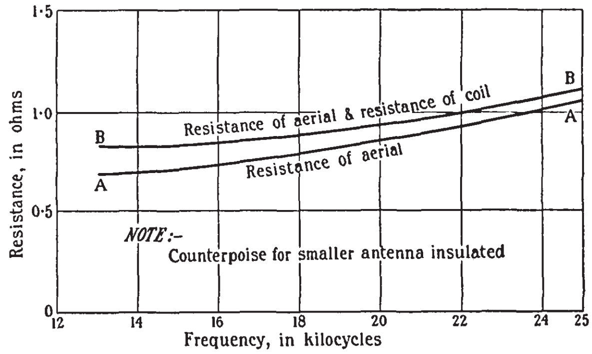

Fig. 7.—Curves of aerial resistance, etc.

Curve AA.—Resistance of telegraphy antenna ($0 \cdot 033\ \mu$F).
Curve BB.—Total resistance of serial circuit with $0 \cdot 033\ \mu$F antenna.

The frequency produced by this means is remarkably constant, the frequency variation with temperature of the tuning-fork being about 1 cycle in 10 000 per degree C. A small adjustable electric heater is provided to enable the temperature of the box containing the tuning-fork to be kept constant.

The "tuning-fork" stages of amplification may be briefly described as follows. The output from the valve-maintained tuning-fork is of the order of micro-watts, and this is amplified once at low frequency. The 9th harmonic is then selected, filtered and amplified three times with low-voltage valves, giving a final output of 100 watts from the last of these three stages. The tuning fork and all the above stages of amplification

* A. G. Lee: *Electrician*, 1925, vol. 94, p. 510.

are contained in two copper boxes mounted one above the other, the various stages being carefully screened from each other by copper partitions, and this complete unit is termed the "tuning-fork unit." The connections of this unit are shown in Fig. 8.

The output from the tuning-fork unit is amplified three times before it is delivered to the aerial circuit, the various stages being designed to deal with input powers of the order of 4 kW, 50 kW, and 1 000 kW respectively, and giving output powers of 2 kW, 30 kW and 540 kW respectively. These are referred to as the 4-kW stage, the 50-kW stage and the "power units" respectively. The combination of the 4-kW stage and its associated 50-kW stage forms an "excitation unit." Excitation units and tuning-fork units are provided in duplicate so as to reduce to a minimum the possibility of delay due to faults, and the arrangement is such that either tuning-fork unit can be used with either excitation unit and either excitation unit can be used to drive the final stage of amplification, which consists of a number of power units.

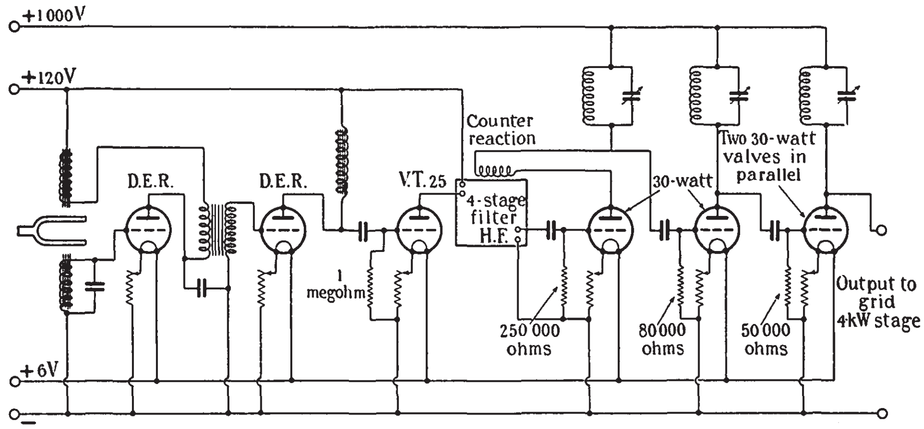

Fig. 8.—Diagram of tuning-fork unit.

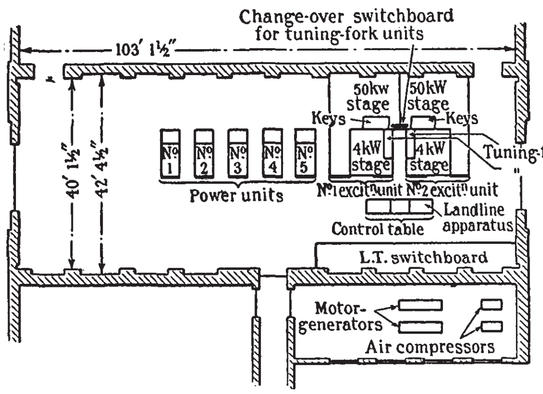

Fig. 9.—Plan of transmitting building.

All the stages and units are contained in high-tension enclosures. The arrangement has been so planned that all meters can be read conveniently, and so that such tuning adjustments as are necessary while the power is on can be made from outside the high-tension enclosures.

Fig. 9 is a plan of the ground floor of the transmitting building and shows the layout of the high-frequency generating plant, etc. The excitation units are seen in duplicate on the right, and the five power units on the left.

The switchboard immediately behind the control table is the 20-panel switchboard, referred to previously, which is associated with the filament supply to the amplifiers and the machines in the auxiliary machine room immediately behind this switchboard which supply the power for the earlier stages of amplification in the tuning-fork unit, the grid bias voltages, compressed-air pump motors, etc.

The main high-tension d.c. switch is remote-controlled from the control table.

The final stage of amplification (i.e. the power units) is not provided in complete duplicate as in the earlier stages. The power-station practice of having a number of units capable of being worked in parallel on common busbars has been adopted. The principal advantages of such a system are :—

(1) It permits an easy flexibility as regards power required for a particular transmission at a particular time of the day, which may be very important from the point of view of not having more valves in use than required and so reducing the consumption of power and also valve replacement costs, which are likely to be a large item in the maintenance costs of the station.

(2) It provides a simple method of repairing a faulty unit or of replacing worn-out or faulty valves while the station is in action.

(3) The installation can be easily adapted to provide either two simultaneous transmission on separate aerials, or a single transmission at larger power on a combined aerial.

(4) It gives facilities for testing different types of valves.

High-Tension D.C. Supply.

The excitation units and the power units are designed to utilize the same voltage high-tension d.c. supply, and a simple arrangement permits this h.t. supply to be switched on to the 4-kW stage, the 50-kW stage and

whichever power units are in use, by the pressing of a single button on the control table, and ensures at the same time that all accessible units are " dead."

(4) The change-over switch of (1) also makes the necessary transfers in the control wiring of (3) as between the excitation units.

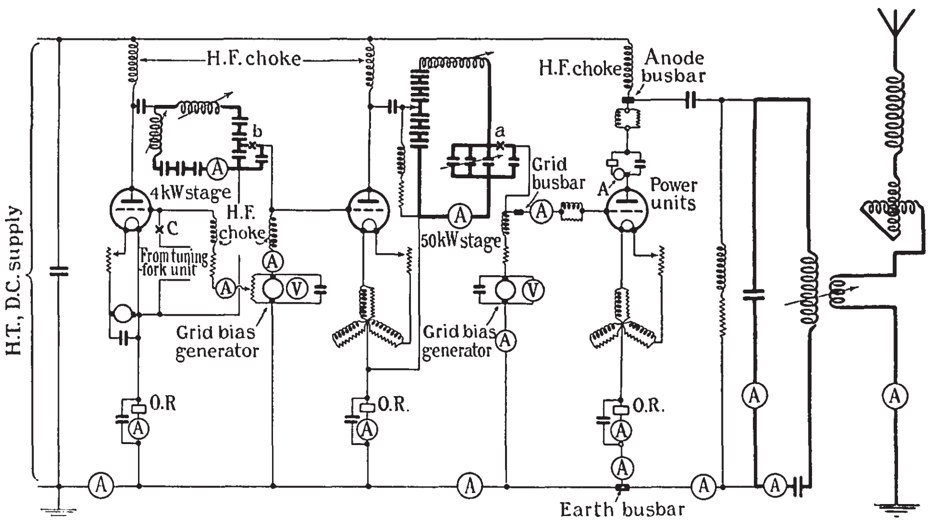

Fig. 10.—Diagram of transmitting circuits.

The general scheme adopted is as follows :—

(1) A change-over switch is provided which connects the h.t. supply to one or other of the excitation units.

(2) The h.t. supply is fed through the excitation unit to the busbar supplying the power units.

(3) All the safety switches and devices form a " series " circuit with the " holding coil " circuit of the high-tension d.c. switch, which is remote-controlled from the control table.

GENERAL SCHEME OF CIRCUITS.

Fig. 10 is a skeleton diagram of the circuit arrangements from the output of the tuning-fork unit to the aerial, showing the circuits between the 4-kW stage and the 50-kW stage, between the 50-kW stage and the power units, and between the power units and the aerial. The tuned high-frequency circuits at the various stages are indicated by the thick lines. A particular characteristic of the circuits is the use of a single tuned circuit between one stage of amplification

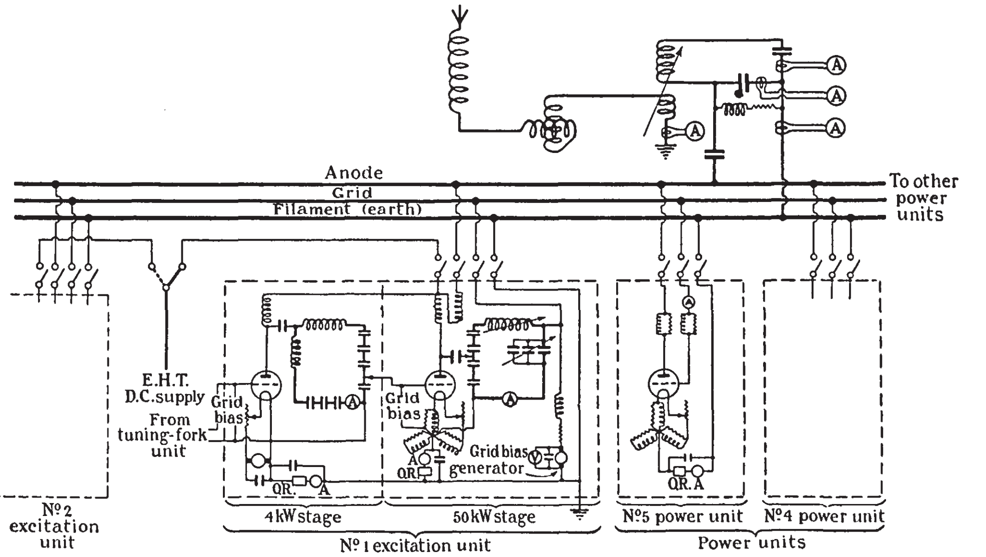

Fig. 11.—Skeleton diagram of arrangement of busbars.

and the next, and the use made of capacitative coupling for giving the necessary voltage variations on both anodes and grids. Some of the advantages of such capacitative couplings are :—

(1) A condenser provides a low-impedance path for the harmonics necessarily generated by a valve transmitter when it is operated as an efficient power amplifier, and thus acts as a desirable harmonic filter.
(2) The actual voltage-swings are easily and accurately calculable both for design and during adjustment.
(3) The power factor of a good condenser being very low, the voltage and current are practically in quadrature.

Fig. 11 is a schematic diagram showing the method of feeding the high-tension d.c. supply through a selected excitation unit to the power units by means of the busbars, and the method of paralleling the power units by means of the same busbars. It will be observed that there are three busbars running the length of the installation for the anode, grid, and filament (earthed) respectively, and that to bring a particular unit into operation in parallel with others it is only necessary to connect it to the busbars by one 3-way switch, and to light the filaments by means of the filament switch for that unit.

In order to simplify this system of paralleling, all apparatus proper to the complete amplifier formed by the power units as a whole, such as anode choke, grid leak, etc., are provided in duplicate and placed inside the respective excitation units.

Filament Supply.

The filament supply for the power units and the 50-kW stage is at 416 volts, three-phase, 100 cycles, transformed down to the required voltage for the filaments (about 20 volts) by transformers in the units themselves. As previously stated, a Tirrill regulator is provided for the 416-volt supply to keep the voltage on the valve filaments constant; this is very important from the point of view of conserving the life of the valves. The filament load of each power unit and each 50-kW stage is balanced between the three phases so as to reduce the effect of any periodic change of emission current due to the use of alternating current for filament heating.

The filament supply for the 4-kW stage is at 15–20 volts d.c. supplied by one of the generators in the auxiliary machine room.

The Excitation Unit.

The 4-kW stage utilizes glass valves of the so-called 600-watt type—i.e. capable of a dissipation of 600 watts —and the panel can be equipped with 1, 2 or 3 of such valves. The valves are mounted on insulators fitted on the back of the slate panel on which the instruments for this stage are mounted.

The 50-kW stage utilizes three water-cooled valves similar to those in the power units, and the manner of mounting, etc., is similar to that of the power units.

The coils forming the inductances of the high-frequency circuits of both stages are constructed of cable of insulated and stranded wires, the cable being wound on a framework of American whitewood in a manner similar to that adopted for the large tuning inductances described later. The cable of the 4-kW stage inductance is 243/36 S.W.G. and that of the 50-kW stage is 729/36 S.W.G. The condensers of these high-frequency circuits are mica condensers in oil.

The safety devices, relays, etc., are similar to those used in connection with the power units.

Associated with each excitation unit is an auxiliary machine unit consisting of one motor driving four generators. These generators have the following ratings and are utilized for the following purposes :—

(1) 500–1 500 volts, $\frac{1}{3}$ amp. Anode supply for various amplification stages of tuning-fork unit.
(2) 15–20 volts, 60 amps. Filament supply for 4-kW stage, and also for tuning-fork unit by means of potentiometer.
(3) 40–600 volts, 12 amps. Grid-bias voltage for power units.
(4) 200–600 volts, 1·5 amps. Grid-bias voltage for 50-kW stage and also for 4-kW stage by means of potentiometer.

The motor driving this unit has a remote-controlled starter so that all the various auxiliary powers required are obtained by the pressing of one button at the control table.

With such a chain of amplifiers as that forming this installation one probable difficulty to be combated is the self-oscillation of the system in whole or part due to retroaction from the later to the earlier stages, but this tendency to self-oscillation can be reduced by very careful screening between the various stages. The tuning-fork unit is made up in the form of two copper boxes with copper partitions between the different stages and tight-fitting copper lids to the various compartments. The excitation units and tuning-fork units are placed inside a screened enclosure, the sides and top of which are formed of copper mesh (14 to the inch) mounted on a suitable framework. Internal partitions of similar copper mesh complete the screening between the tuning-fork unit, the 4-kW stage and the 50-kW stage respectively.

Considerations in Regard to the Size of Power Unit.

The number of valves used for a high-power valve transmitter should be reduced to a minimum by using the most powerful valve available as a unit. When the design for Rugby was prepared, the largest power valve commercially available which had been subjected to severe traffic tests was the Western Electric water-cooled valve which is capable of dealing with an input of 20 kW, of giving an output of 10 kW and continuously dissipating 10 kW when operated at a d.c. anode voltage of 10 000 volts—the filament consumption being 41 amperes at 22 volts. This type of valve had been tested to 13 000 volts with an output of 14 kW. The specification stipulated that all valves should be tested at an output of 12 kW with 12 000 volts on the anode. All the valves used in the installation were manufactured by the Western Electric Co. at New Southgate, England.

An efficiency of the order of 95 per cent can be expected from the coupled circuit to the antenna, which means that for an aerial power of 500 kW an output from the valves of about 520–530 kW is required. The determining factors in deciding the size and number of the power units were as follows :—

(1) The number of valves in each unit should be preferably a multiple of 3 in order to permit the balancing of the filaments between the three phases.
(2) The number of units must not be unduly large, in order to avoid complications of wiring and excessive duplication of meters, etc.
(3) The number of units should be sufficient to enable the number of valves in use to be varied in suitable steps (*a*) for the station to work on low power if this proves to be economically desirable, or (*b*) for the utilization of a smaller number of greater power valves as the manufacturing technique of power valves develops.
(4) The number of units should be suitable to provide two transmissions of the order of 300 kW aerial power and still leave a spare unit.

These considerations led to the decision to provide 5 power units, each capable of an output of 180 kW from 18 10-kW output water-cooled valves. With this equipment 3 power units would be required for a 500-kW aerial power transmission, leaving 2 units spare ; also two transmissions of over 300 kW aerial power could be undertaken by using 2 power units for each, leaving one unit as a spare in reserve.

The Power Unit.

The power unit consisting of 18 valves is a rectangular enclosure arranged with 9 valves on each side and a front slate panel containing the meters.

The 3 busbars run above the various power units and the excitation units and each power unit can be connected to the busbars by a 3-pole switch. The 3-pole switch for connecting a power unit to these busbars cannot be operated until the Bostwick gates on the sides of the unit have been closed and locked, and the keys locked in the switch itself ; the converse holds that the gates of the unit cannot be opened until the keys for opening them have been released by the opening of the switch, which " earths " all parts of the power unit. These interlocking devices render the operation of the power units quite safe.

The front panel of a power unit carries the following :—

(1) Ammeter reading high-frequency feed current from the power unit into the oscillating circuit.
(2) Ammeter reading anode d.c. feed current to power unit from high-tension machines.
(3) Ammeter reading mean d.c. grid current of power unit.
(4) Recording ammeter of filament current, by means of which the actual running time of unit and the life of individual valves can be obtained.
(5) An overload relay for the complete power unit which trips the main high-tension d.c. switch.
(6) An " Electroflo " meter which reads the actual total rate of flow of water through the valve jackets of the unit.
(7) A relay in association with the " Electroflo " meter which operates if the flow of water falls below a certain amount, and trips the main high-tension d.c. switch.

Fig. 12 is a section through a power unit parallel to the front, showing the juxtaposition of the various panels. Slate panels have been used in all cases for mounting the various apparatus and fittings, these slate panels being supported and insulated from the earthed iron framework by suitable porcelain insulators.

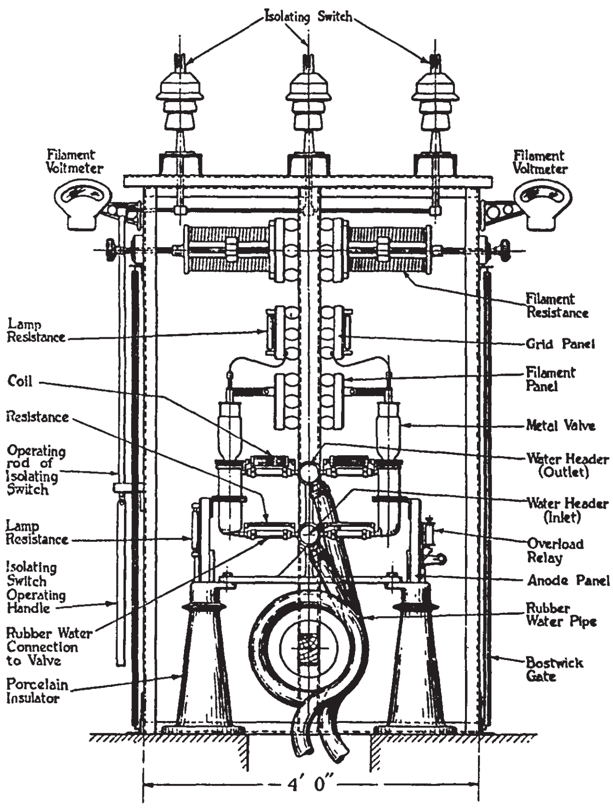

FIG. 12.—Section of power unit.

The two anode panels are supported from the floor by four 18-in. insulators. These insulators also support the copper water pipes between these panels which not only act as headers for the water supply to the anodes but also as the anode busbars for the valves in the panel.

The anode panels carry the valves in their water jackets and the overload relays in the individual anode circuits. In the event of any particular valve taking an excess current due to softness or any other reason, the corresponding relay operates, releasing a hammer normally held up by the armature of the relay, which in turn operates a mechanism that trips the high-tension d.c. switch by breaking the " holding coil " circuit. The arrangement has proved to be very effective, and oscillograms which have been taken show that the h.t. switch is broken in about $\frac{1}{4}$ sec. following an excess of current through the relay.

The water system used for cooling the anodes is a closed system using distilled water which flows by gravity through the valves. The water is pumped from the bottom tank back to the upper supply tank through a "water cooler," where the heat is extracted by an independent circulating-water system.

The distilled water is supplied to the anodes of the power unit through 30 ft. of 2-in. diam. rubber hose wound on a horizontal wooden drum at the bottom of the power units. This rubber hose feeds the 3 in. copper header which passes down through the centre of the unit and which in turn feeds the individual valves on each side through short lengths of rubber tubing to the lower ends of the valve jackets. The outlet water from the upper ends of the valve jackets passes to a similar header which discharges through another length of 2-in. hose similar to that used for the inlet water and wrapped round the same drum. The long length of water in the rubber hose provides the necessary insulation of the anodes from the earthed metal parts of the water cooling system, and the drum carrying this hose is a part of the insulated anode system. The short lengths of rubber tube from the headers to the valves provide the insulation required between valves to permit the insertion of relays, coils, etc., in the individual valve anode circuits. The porcelain floor insulators and the large rubber hose are shown in Fig. 12.

The insulation of the anode system of one power unit under working conditions with water flowing is of the order of 520 000 ohms, giving a leakage current through the water of only 20 mA at 10 000 volts.

Immediately above the anode panels are the filament panels which carry the filament busbars for the unit and the flexible braided leads from these busbars to the separate valve filaments. Above the filament panels are the grid panels, which carry the grid busbar (in the form of a complete loop of copper strip between the panels) and also any "stopper" circuits referred to later.

Above the grid panels are the filament rheostats, one of which is provided for each valve, together with a voltmeter key to enable the actual filament voltage to be read by means of a swinging voltmeter at the end of the panel. This independent variation of the filament voltage in order to obtain the rated value for each valve is very necessary in order to conserve the life of the valves, the life being seriously shortened if the filament is continuously run slightly above its rated voltage.

The Paralleling of Valves in a Unit.

One of the difficulties in designing a large power transmitter using a large number of valves is the tendency of such valves to "self-oscillate," individually or in groups, the inter-electrode capacity of adjoining valves or groups of valves forming the condenser of the oscillating circuit in association with the inductance of the connecting leads, etc. These difficulties are increased with water-cooled valves where the existence of the water jacket increases the inter-vale and inter-electrode capacities very considerably. Every such difficulty of this nature must be examined and dealt with separately, and, generally speaking, the oscillations can be suppressed and the system made stable by one or more of the following devices :—

(1) The provision of a small condenser between the grid and filament of each valve, as close to the electrodes as possible, in order to make the grid-filament impedance capacitative.

(2) The use of "stopper" circuits in the individual anode, and/or grid circuits consisting of an inductance in parallel with a resistance high compared with the impedance of the inductance at the transmitted frequency. For undesired oscillations, however, which are of a much higher frequency, the added inductance becomes a large proportion of the inductance of the circuit, and the resistance across it provides sufficient damping for the conditions of self-oscillation of the valves to be unfulfilled (Western Electric Co.).

(3) The insertion of a series resistance in the individual anode or/and grid circuits which act as a damping for self-oscillation but are not of high enough value to cause a large power loss at the transmitted frequency.

The best arrangements for a particular case must be obtained by experiment, and quite a number of combinations of such devices would probably be equally successful. It is generally desirable to allow a factor of safety on such devices by fitting more than the minimum absolutely essential, so as to provide for the contingency of faults which might otherwise permit self-oscillation, with the consequent possible destruction of a number of costly valves.

The arrangements used successfully at Rugby are :—

(1) Two small condensers of 400 $\mu\mu$F each are mounted on each valve between the grid and each end of the filament.

(2) A series non-inductive resistance of 100 ohms between each individual grid and the grid busbar.

(3) The anode feed from the individual valves to the top water header (which acts as the anode busbar) consists of an inductance of 50 μH in parallel with a non-inductive resistance of 60 ohms to the same header and a similar non-inductive resistance to the bottom water header, these two headers being metallically connected at the end of the panel.

Fig. 13 gives the circuit arrangements of a complete power unit.

The Paralleling of Power Units.

The paralleling of the power units themselves also involves consideration as to the method of prevention of inter-oscillation between power units.

At Rugby the combined anode of the power unit is fed to the main anode busbar through a "stopper" circuit consisting of an inductance of 100 μH in parallel with a resistance of Morganite plates of 8·5 ohms. The combined grid of the power unit is fed to the main grid busbar through a "stopper" circuit consisting of an inductance of 50 μH in parallel with a resistance of 300 ohms formed by 6 straight-filament lamps in series. The positions of these in the circuit are shown in Fig. 13.

These " stopper " circuits are fitted at the back of the power unit in the space above the filament transformer and immediately below the 3-pole power unit isolating switch, to two terminals of one side of which they are connected.

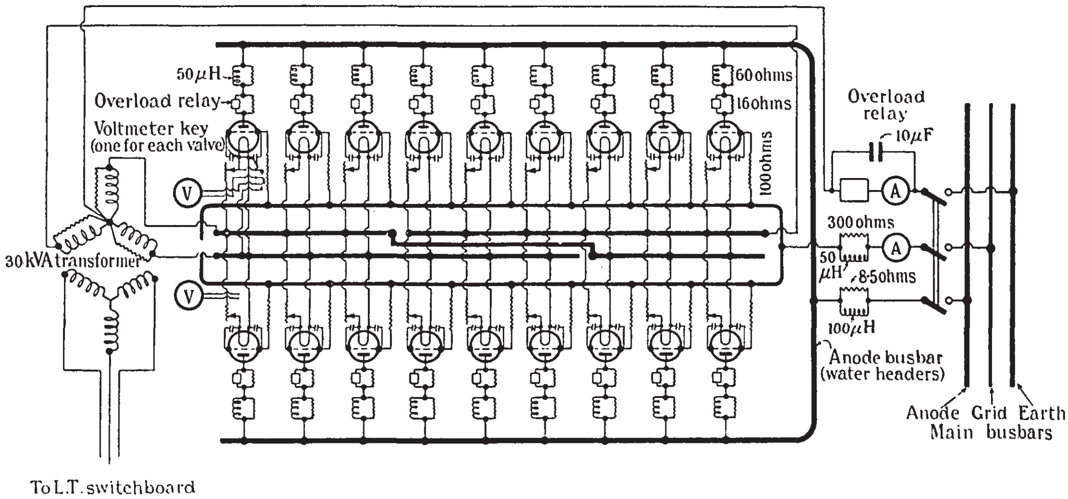

FIG. 13.—Wiring diagram of power unit.

SAFETY DEVICES AND CONTROL CIRCUIT.

The safety devices can be divided into two groups :—

(1) Those for the protection of the personnel.
(2) Those for the protection of plant.

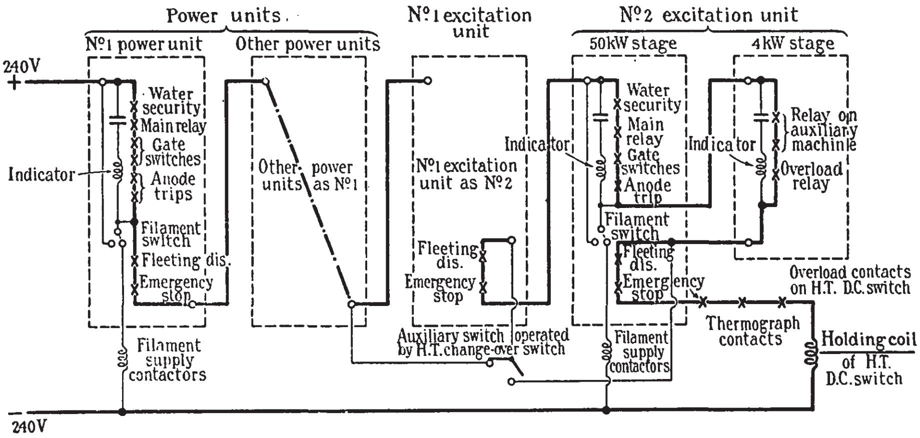

FIG. 14.—Skeleton diagram of control circuit.

For the protection of personnel, the interlocking of the gates of the power units as described previously, and the earthing of the unit when the isolating switch is open, safeguard the station staff from electric shock when working on the power units. A similar arrangement is provided in connection with each excitation unit. The 4-pole isolating switch (see Fig. 11) which connects the high-tension d.c. power to the excitation unit, and the excitation unit to the main busbars is similarly interlocked with the gates of the excitation unit enclosure.

The protection of plant is of special importance when using valves, because, firstly, the closing of the h.t. switch for a very short period under incorrect conditions might result in the destruction of a number of valves, and secondly, there is a possibility of valve failures which amount to a short-circuit of the 10 000-volt d.c. supply. All the safety devices and relays are therefore linked up in one series circuit through the " holding " coil of the high-tension d.c. switch. A disconnection in any one place will then prevent the switch from being closed, and also the breaking of the circuit at any point during transmission due to a fault or an overload will open the high-tension d.c. switch.

Fig. 14 is a skeleton diagram showing the circuit arrangement of this " series " control wiring through the " holding " coil of the high-tension d.c. switch. The main facts to be noticed in connection with it are as follow :—

(1) The series circuit includes one of the two excitation units and whatever power units are in use.
(2) The operation of the hand-operated switch which changes over the h.t. supply from one excitation unit to the other automatically changes over the control wiring and short-circuits that of the excitation unit not in use to permit access for repairs, adjustments, etc.
(3) The placing of the filament switch on a power unit to the "off" position short-circuits the control wiring of that particular unit, and enables work to be done on that unit while the others are in use.

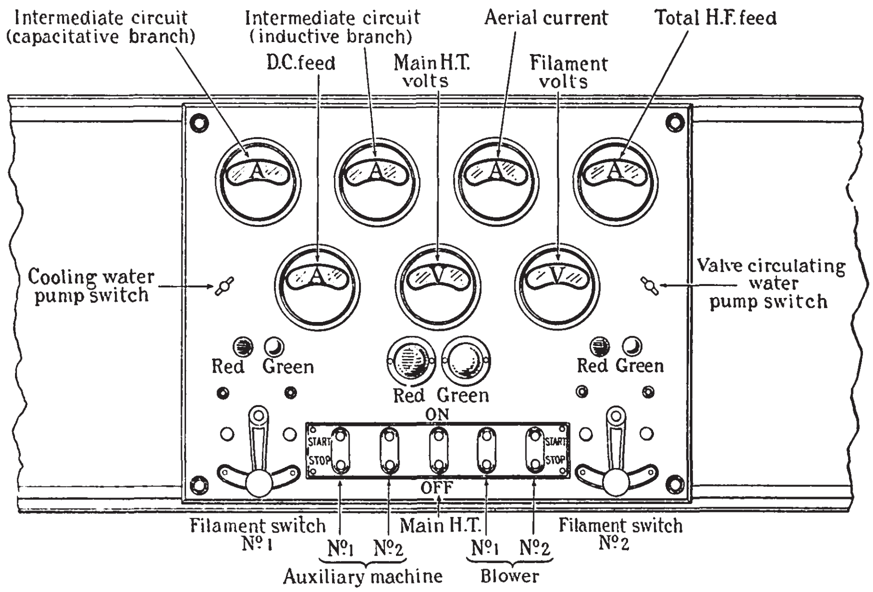

FIG. 15.—Control table.

(4) The placing of the filament switch on a power unit to the "on" position connects the primary of the filament transformer to the filament supply busbars by means of a remote-controlled contactor. The 240-volt supply to operate this contactor is obtained via the control wiring as shown in the diagram, thus ensuring that the filaments cannot be lighted until water flowing through the valve jackets has closed a contact earlier in the circuit.
(5) An indicator is fitted on the front of each power unit panel and placed in series with a condenser across all the contacts of that particular unit. When a break in the control circuit occurs, the charging current from the 240-volt mains into the condenser drops the indicator and gives a visual indication of the particular unit at which the overload or other trouble has occurred.

The operating points of the control circuit may be summarized as follows :—

(1) *On each power unit.*
(*a*) Main overload relay.
(*b*) Trip operated by individual anode relays.
(*c*) Water-flow relay.
(*d*) Gate switches.
(*e*) A fleeting disconnection during the movement of the power unit isolating switch, to ensure that a unit is not switched on to the busbars while other units are in operation.
(*f*) Emergency push-button.

(2) *On each excitation unit.*
(*a*) Main overload relay for 50-kW stage.
(*b*) Trip operated by individual anode relays of 50-kW stage.
(*c*) Water-flow relay for 50-kW stage.
(*d*) Overload relay for 4-kW stage.
(*e*) Gate switches.
(*f*) A fleeting disconnection for the excitation units similar to that of (1*e*) for power units.
(*g*) A polarized relay in association with one of the grid-bias generators to ensure that the auxiliary machine is running and that the bias is of correct polarity.
(*h*) Emergency push-button.

(3) *External to power and excitation units.*
(*a*) A contact in association with a recording thermograph which records the temperature of both the inlet and outlet temperature of the valve-cooling water. This contact is arranged to open if the outlet water exceeds a predetermined temperature.
(*b*) Emergency switch in condenser room.
(*c*) Overload coil of high-tension d.c. switch.
(*d*) Release button on control table.

THE CONTROL TABLE.

The position of the control table in the layout of the transmitting room can be seen from Fig. 9. The slate panel contains all the essential controls and the most important meters of the wireless transmitter. This equipment is shown in Fig. 15 and consists of :—

(1) Press-buttons to start and stop auxiliary machines.
(2) Press-buttons to start and stop air compressor for keys.
(3) Press-buttons to close and open high-tension d.c. switch.
(4) Switch to start distilled-water pump.
(5) Switch to start cooling-water pump.
(6) Switch to close and open main filament supply switch.
(7) Filament supply voltmeter.
(8) High-tension d.c. voltmeter.
(9) High-tension d.c. feed ammeter.
(10) Ammeter reading high-frequency feed current to main oscillating circuit.
(11) Ammeter reading high-frequency current in capacitative arm of primary oscillating circuit.
(12) Ammeter reading high-frequency current in inductive arm.
(13) Aerial ammeter.

The apparatus terminating the land line from the Central Telegraph Office, London, which controls the transmission from the station, is fitted on the right-hand side of the control panel so that the duty engineer can check the signals passing through the transmitter and also speak to the controlling telegraph office as may be necessary.

On the table on the left-hand side of the control panel is fitted an " engine-room telegraph " operated by push-buttons to enable the power requirements to be signalled to the power house. A loud-speaker and wireless recorder are provided for checking the actual signals transmitted from the aerial. In addition there are fitted on this table, two press-buttons controlling a motor-driven variometer in the aerial circuit to compensate for any changes in the aerial constants due to weather, etc.

The duty engineer, therefore, has full control of the entire station in detail from his position at the control table.

The high-frequency and other electrical measuring instruments fitted in the valve transmitting plant were supplied by Messrs. Everett, Edgcumbe.

Type and Electrical Proportions of Coupled Aerial Circuit.

Any large power valve transmitter should be provided with a coupled circuit, since the use of a valve transmitter at reasonably high efficiency necessitates the production of a certain proportion of harmonics, which should be filtered from the aerial. This involves a consideration of the following points :—

(1) Method to be adopted to produce necessary voltage variation on anode (commonly referred to as " type of anode tap ").
(2) Method of coupling to aerial, i.e. inductive or capacitative.
(3) Coefficient of coupling between aerial and primary circuit.
(4) Proportion of inductance to capacity in primary circuit.

The diagrams of Fig. 16 * indicate various circuit arrangements which are referred to as Types A, B, C, D and E respectively.

For an " anode tap " the use of a capacity rather than inductance brings with it a reduction of the harmonics in the aerial in the ratio of $1/m^2$ for the mth harmonic ; that is, types B and D are m^2 times better than types A and C respectively. For preliminary tuning, the use of capacity rather than inductance brings with it the disadvantage of having to be tapped in relatively big steps instead of being continuously variable

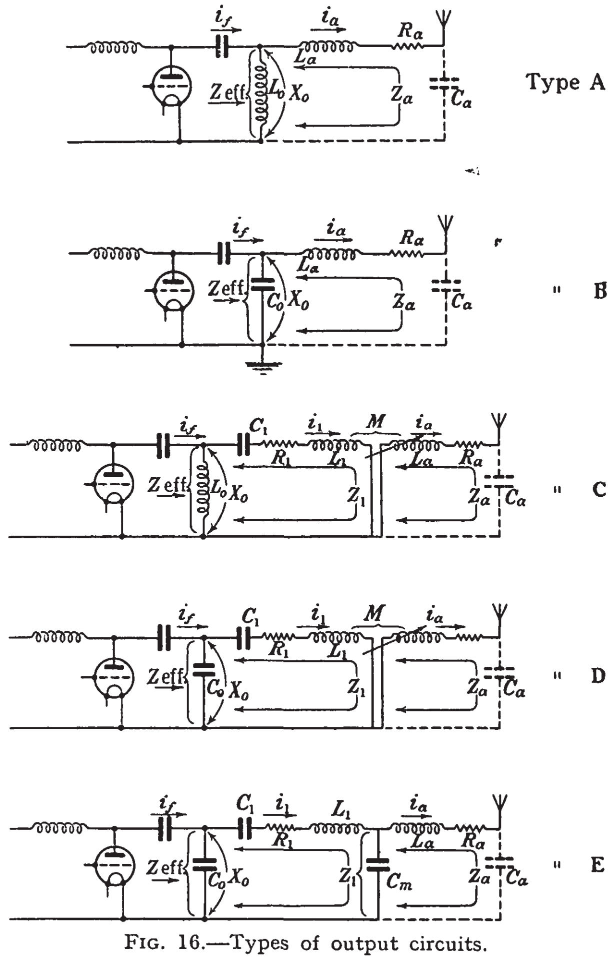

Fig. 16.—Types of output circuits.

as with an inductance ; but, within these steps, variations of coupling between the primary circuit and the antenna circuit will produce equivalent changes in the adjustment of the complete circuit.

Similar arguments apply to the method of coupling the primary circuit to the antenna circuit ; that is, as regards the undesirable emission of harmonics, type E circuit is m^2 times better than type D, and therefore m^4 times better than type C. The ideal circuit, therefore, from the point of view of harmonic emissions is that shown as type E with capacitative coupling to both anode and aerial.

In practice, however, when designing a circuit for an

* The author is indebted to Mr. R. V. Hansford and Mr. Faulkner for these diagrams.

aerial not yet erected of which the resistance and capacity are not known accurately, it would be expensive to provide a range of condenser values for both anode and aerial couplings which would cover both all the large and small adjustments required during the experimental period of tuning up the plant. If, however, a type D circuit is used with a condenser having a relatively coarse adjustment for the anode coupling and a continuously variable inductive coupling for the aerial, all necessary adjustments for the preliminary testing can be made with facility; then when the constants of the aerial circuit are known and the preliminary tuning has been completed, if necessary the change from type D to type E can readily be made. It has, however, been found unnecessary to depart from the type D circuit installed.

As regards the emission of harmonics, the improvement obtained by using a coupled circuit of type D instead of a plain aerial circuit is dependent, among other factors, upon the product of the decrements of the primary and aerial circuits. When a low-decrement aerial tuning inductance is provided, the decrement of the aerial circuit at a given frequency is practically fixed, being mainly dependent upon the external part of the circuit.

It is therefore important that the decrement of the primary circuit be made low, and this involves the provision of the most efficient inductance coil and condensers having very low loss. The cost of the primary circuit is roughly proportional to the kVA with which it has to deal, except at the higher voltages where the cost increases rather more rapidly than the kVA.

The efficiency of the coupled circuit and the improvement as regards harmonic emission obtained by using the coupled circuit are both independent of the ratio of inductance to capacity in the primary circuit. Under these circumstances the actual value of the inductance was chosen from a consideration of the following :—

(1) The cost of the coil decreases slightly as its inductance is decreased.

(2) Above a certain working voltage the cost of the condenser increases at a more rapid rate than its capacity.

(3) The cost and difficulty of insulating leads are increased when high working voltages are increased.

This led to the decision to have a primary circuit inductance of the low value of 500 μH. The values of the condensers making up the primary oscillating circuit are given in Fig. 17. The condensers used are mica condensers immersed in oil, made by Messrs. Dubilier to meet the Post Office specification. These have a power factor of 0·00025 at the working frequency. The power factor was tested by an 8-hours' run on each unit on full load and voltage at the maker's works. In addition to the power factor tests each unit of the condenser banks (Fig. 17) was tested at the following voltages :—

Bank A—68 000 volts (R.M.S.) at 50 cycles.
Bank B—25 000 volts (R.M.S.) at 50 cycles.
Bank C—35 000 volts (R.M.S.) at 50 cycles.

The primary circuit is designed to carry a current of 630 amperes, and at this current the value of the R.M.S. voltage applied to the condenser would be 33 000 volts (peak value 46 500 volts) and the kVA 20 800. Actually at present the value of the working primary current is about 300 amperes.

At Leafield the condensers, consisting of aluminium plates immersed in oil and made and erected by the Post Office engineers, have been working for about 2 years with a current of 260 amperes and a voltage of 68 000 (R.M.S.), dealing with 18 000 kVA. The Dubilier type of condenser is much less bulky than the Leafield type and its adoption enabled space to be saved in the Rugby building.

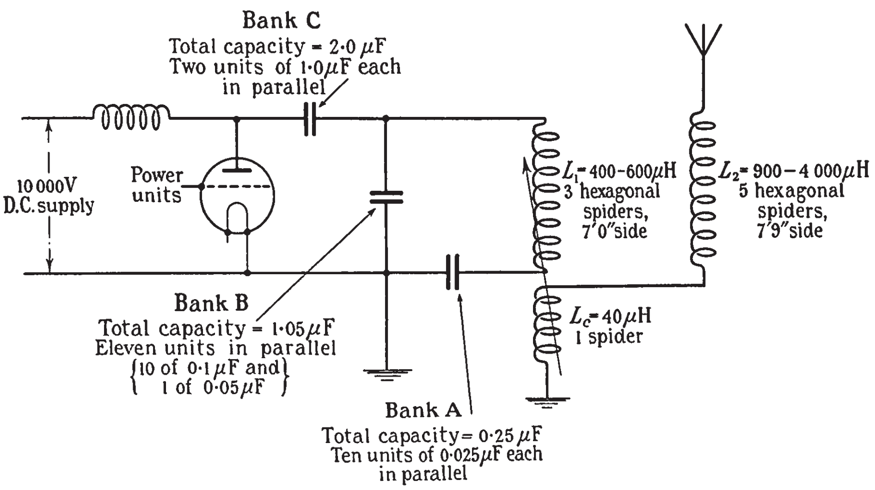

FIG. 17.—Coupled aerial circuit.

THE DESIGN OF INDUCTANCES FOR HIGH POWERS.

It is essential in a high-power transmitting station that the losses in the primary-circuit and aerial-circuit

inductances should be reduced to a minimum. The losses which add together to form the equivalent resistance of the coil may be divided into the following three groups :—

(1) Losses in the conductor itself.
(2) Losses in surroundings.
(3) Losses in the framework necessary to support the conductor forming the inductance.

The losses in the conductor itself (group 1) have been discussed mathematically in detail by Mr. Butterworth,* and although Mr. Butterworth does not deal with the case of a large coil with widely spaced turns in a deep winding space, the formulæ he has given can be used without serious error *to compare* the efficiency of various designs of coils, etc. At the time the designs were being prepared the practical manufacturing limit as regards number of strands in a cable was 6 561 ($= 3^8$) and for this number of strands, so far as conductor losses only were concerned, calculations indicated that the diameter of the coil should be as great as the limitations of the space permitted and the diameter of the wire used should be very small and of the order of 0·007 in. It was therefore decided to use a cable of 6 561 strands of No. 36 S.W.G. wire for both the primary and aerial inductances, each strand being insulated by enamel and one covering of cotton or silk. The cables were made to the Post Office specification by Messrs. Henleys Telegraph Works Co., Ltd., and Messrs. Connollys, Ltd. The maximum current-carrying capacity of this cable when wound into an inductance is probably of the order of 1 000 amperes.

With an efficiently designed coil of large dimensions for big powers, the losses in the surroundings and in the inductance framework must necessarily be of the same order as the conductor losses. The losses in the surroundings can only be reduced by having adequate clearances between the inductance and the floors and walls, and by avoiding as far as possible for the construction of the building the use of materials which are likely to absorb energy from the inductances.

A considerable amount of experimental work † has been carried out in the Post Office Engineering Department to ascertain a suitable insulating material for use in the construction of radio transmitting inductances, and it was found that American whitewood was very much better as regards dielectric losses than any other material or any other wood. The method adopted by the Post Office for the construction of transmitting inductances is to mount a cable formed of insulated and stranded wires on a framework of American whitewood. The cable is wound in slots on movable wooden spiders which are supported by rollers on a wooden framework, so that changes of inductance can be obtained by the relative movement of the spiders without the awkward mechanical construction of "tapping points" and the disadvantages of "overhanging" end-turns. The maximum width of the largest inductance coil is 14 ft. 6 in. The particulars and general dimensions of the aerial and primary circuit inductances are as follow :

* *Philosophical Transactions of the Royal Society*, A, 1921, vol. 222, p. 57.
† E. H. Shaughnessy : Chairman's Address to the Wireless Section, *Journal I.E.E.*, 1925, vol. 63, p. 60.

Aerial coil.—This consists of 5 spiders each of 8 turns wound in the form of a hexagon with 7 ft. 9 in. external side (5 ft. 9 in. mean side). Distance between individual turns 6 in. Inductance continuously variable between 900 and 4 000 μH.

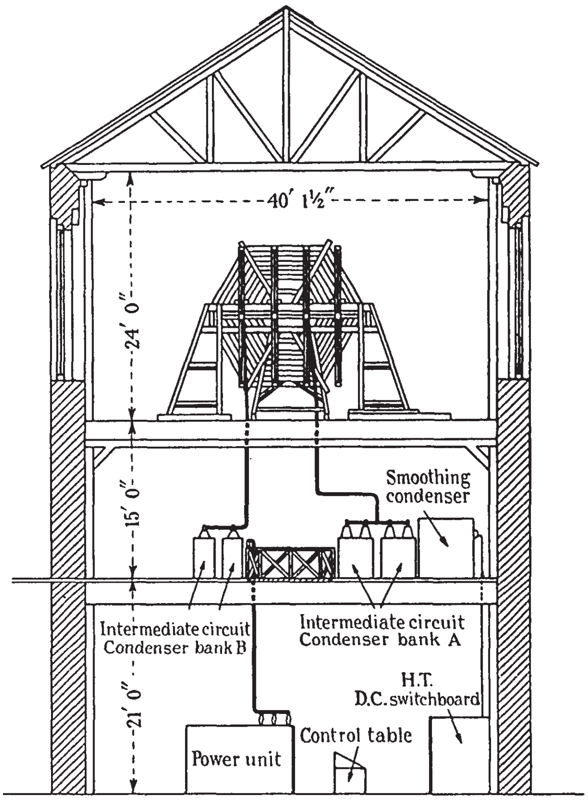

Fig. 18.—Section of transmitting building.

Primary circuit coil.—This consists of 3 spiders each of 4 turns wound in the form of a hexagon with 7 ft. external side (6 ft. 2 in. mean side). Distance between turns 6 in. Inductance continuously variable from 400 to 600 μH.

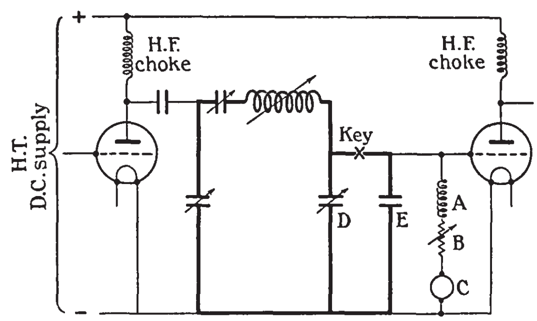

Fig. 19.—Skeleton diagram of inter-stage circuit.

Coupling coil.—One spider wound with 2 turns 6 ft. 5 in. external side. This coil is mounted on the same framework as the intermediate circuit coil and is coupled thereto. Inductance 40 μH.

One outside spider can be moved by a screw in order to get a fine adjustment of tuning. The method of

making a joint in the stranded wire between the spiders is to splay out the strands on a number of insulated flat copper plates and semi-conical copper fittings so as to ensure proper circulation of current through all the strands and to keep a cool joint.

It was estimated at the time of the design, from previous comparisons between actual and calculated decrements of smaller coils, that the decrement of the complete primary circuit would be about 0·003 to 0·005 and that of the aerial tuning inductance would be about 0·002. The actual measured resistance at 16 000 cycles of the entire primary circuit as erected was 0·088 ohm, giving a decrement of 0·0053. The measured resistance of the aerial tuning inductance and coupling coil (2 500 μH) at 16 000 cycles was 0·11 ohm, giving a decrement of 0·00137 for the coils. These values of decrements are very low and the author has not noticed details in the technical Press of any transmitting inductance which is as efficient as these have proved to be.

Relative Positions of Various Amplifiers and Aerial Circuit.

Fig. 18 is a section of the transmitting building, showing the relative positions of the power units and their output circuit. It will be noticed that the condensers of the primary circuit and the smoothing condensers on the high-tension d.c. supply are placed on a floor immediately above the power units. A large opening is provided in this floor for light and observation purposes, and the high-frequency leads from the ground floor to upper floors are taken through this.

The inductances for the primary and aerial circuits are mounted on wooden beams above the condenser floor. This arrangement places the inductances as far as possible from the floors, walls, etc. The metal work used in the construction of the building above the condenser floor is reduced to a minimum, and is a negligible quantity.

Method of Keying and Shape of Signals.

One of the greatest difficulties experienced in the design of any type of large-power radio transmitter is that of successful keying, and in each case the best method and best adjustment are obtained by experience and experiment. A considerable amount of experimental work on various methods of keying a valve transmitter was carried out with the 50-kW transmitter at the Post Office Northolt radio station, and as a result of those experiments it was decided to provide for the simultaneous operation of a simple "make and break" key at each of the three points in the circuit marked X in Fig. 10. The system has proved to be eminently satisfactory and no difficulties have been experienced up to the highest powers used at present. Creed pneumatic keys are used for points "a" and "b," and a magnetic relay for point "c."

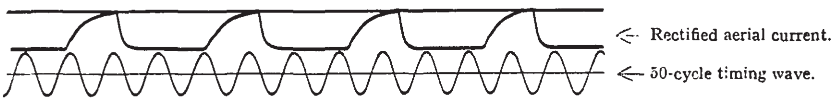

Fig. 20.—Oscillogram of rectified aerial current.
[Aerial current = 515 amps.]

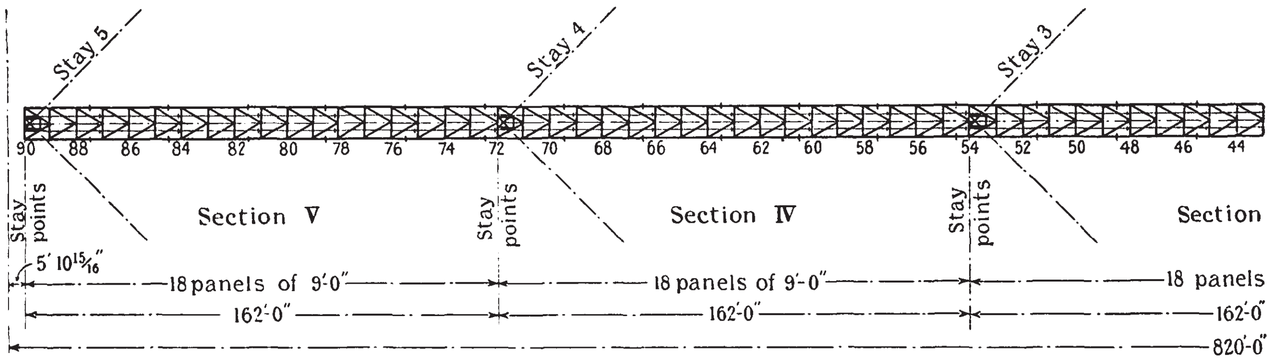

Fig. 21.—Elevation of mast.

It will be observed that there is no oscillation in the aerial when the key is "up," and that this result is obtained by breaking the feed to the grid from one stage of amplification to the next, as shown in Fig. 19, which is a skeleton diagram of the last inter-stage circuit.

There are two points of particular interest in the arrangement. The first is that the key splits the coupling condenser to the grid and leaves the condenser E between the grid and filament when the key is up. This condenser is of sufficient value to make the impedance from grid to filament capacitative, and this counteracts any tendency that this stage may have to self-oscillate.

The second point of interest is the series circuit A B C from grid to filament. "A" is merely a high-frequency choke, "B" is an adjustable resistance (grid leak) and "C" is a d.c. (grid bias) generator. When the key is down, the mean negative grid potential is the sum of that due to the grid leak and the generator; when the key is up, the only bias is that due to the generator.

By adjusting the proportions of the bias due to grid leak and generator respectively when oscillating, it can be arranged that the generator voltage is sufficient to allow a suitable direct current to pass through the valves when the key is up. The advantages of this are two-fold and are shown below :—

(1) The d.c. load with " key up " reduces the voltage " kick " on the generator with keying.
(2) The conductive path through the valve (due to the small grid bias) increases the damping of the aerial when the key is up, with a corresponding improvement in the shape of the signals.

The latter point is well illustrated by the group of oscillograms in Fig. 20, which shows the shape of the signal in the aerial for a series of dots at about 50 words per minute. The oscillogram of the rectified aerial current obtained from a local circuit shows quite clearly the different rates of change for growth and decay respectively of the aerial current.

From similar oscillograms of the aerial current the decrement of the aerial circuit for the rise of current has been calculated as being 0·0086, whilst for the decay it is as high as 0·024. The advantage of this method of keying as regards shape of signals is therefore quite obvious; the oscillogram indicates that, for higher speeds, advantage should be taken of the quick decay by decreasing the length of the " space " relatively to the " mark," and means for doing this are being developed. This method of keying is due to Messrs. Hansford and Faulkner.

The whole of the work of erecting and assembling the internal wireless plant, including the excitation units, valve panels, power units, oscillating circuits, and the winding and jointing of most of the inductance coils, was done by Post Office workmen under the supervision of, and to the detailed designs of, Post Office engineers. The tuning-fork units were made in the Post Office experimental workshop at Dollis Hill.

MASTS.

The masts are 820 ft. in height from ground-level to the top of the antennæ aerial sheave and are of the stayed and pivoted type, insulated at the base (see Fig. 21). The pivot is about 17 ft. above ground-level; below this are columns of porcelain insulators and a granite cube (5 ft. 6 in. sides), the whole being supported by a steel column the top face of which is 8 ft. 2 in. above ground. The masts are of triangular form with 10 ft. sides, the vertical posts being formed of two channels fastened together at an angle of 60° by a bent bar plate. The bracing is arranged in panels 9 ft. high and is of the K form.

Five sets of stays, 3 per set, are provided and divide the mast into 5 sections.

The mast is not tapered, but the mast sectional members are gradually diminished in size at each stay point from the bottom to the top of the mast.

The principal dimensions of the mast sections are :—

Vertical posts.
Channels—Bottom section, 10 in. × $3\frac{1}{2}$ in. × 28·2 lb.
Top section, 5 in. × $2\frac{1}{2}$ in. × 11 lb.
Bent bar plate—Bottom section, 8 in. × $\frac{1}{2}$ in.
Top section, 6 in. × $\frac{3}{8}$ in.
Bracing angles.—Bottom section, 4 in. × 4 in. × $\frac{1}{2}$ in.
Top section, $3\frac{1}{2}$ in. × $3\frac{1}{2}$ in. × $\frac{3}{8}$ in.

The masts were designed to withstand a uniform wind load of 60 lb. per sq. ft. of projected surface, and a horizontal antennæ pull of 10 tons at the top. The maximum heel or deviation from the vertical allowed under load was 1 per cent, i.e. 8 ft. at the top of the mast. It was specified that the maximum compressive stress in lb. per sq. in. was not to exceed

$$18\,000 - 80\ l/r$$

when l/r is equal to or exceeds 50, and not to exceed 14 000 lb. per sq. in. for ratios of l/r less than 50, where l is the length of the post between bracings, or the distance between stays, and r is the least radius of gyration of post or mast section. Under these conditions the maximum bending moment occurring at any section was 400 tons-ft. and the maximum shear force 15 tons. Throughout the length of the mast below the top stay the compressive load due to the weight of the structure and the vertical component of the stay tensions always exceeds the tensile load due to bending moment, and the posts are therefore always in compression.

The total weight of steelwork in a mast is 170 tons, and the weight of the 15 stays is 28 tons and stay anchorages, etc., 12 tons. Under maximum wind load

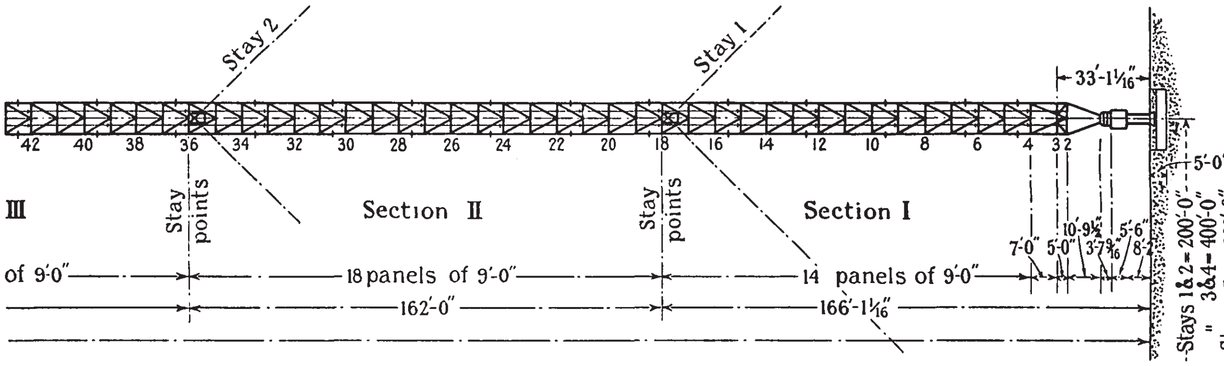

FIG. 21 (*continued*).

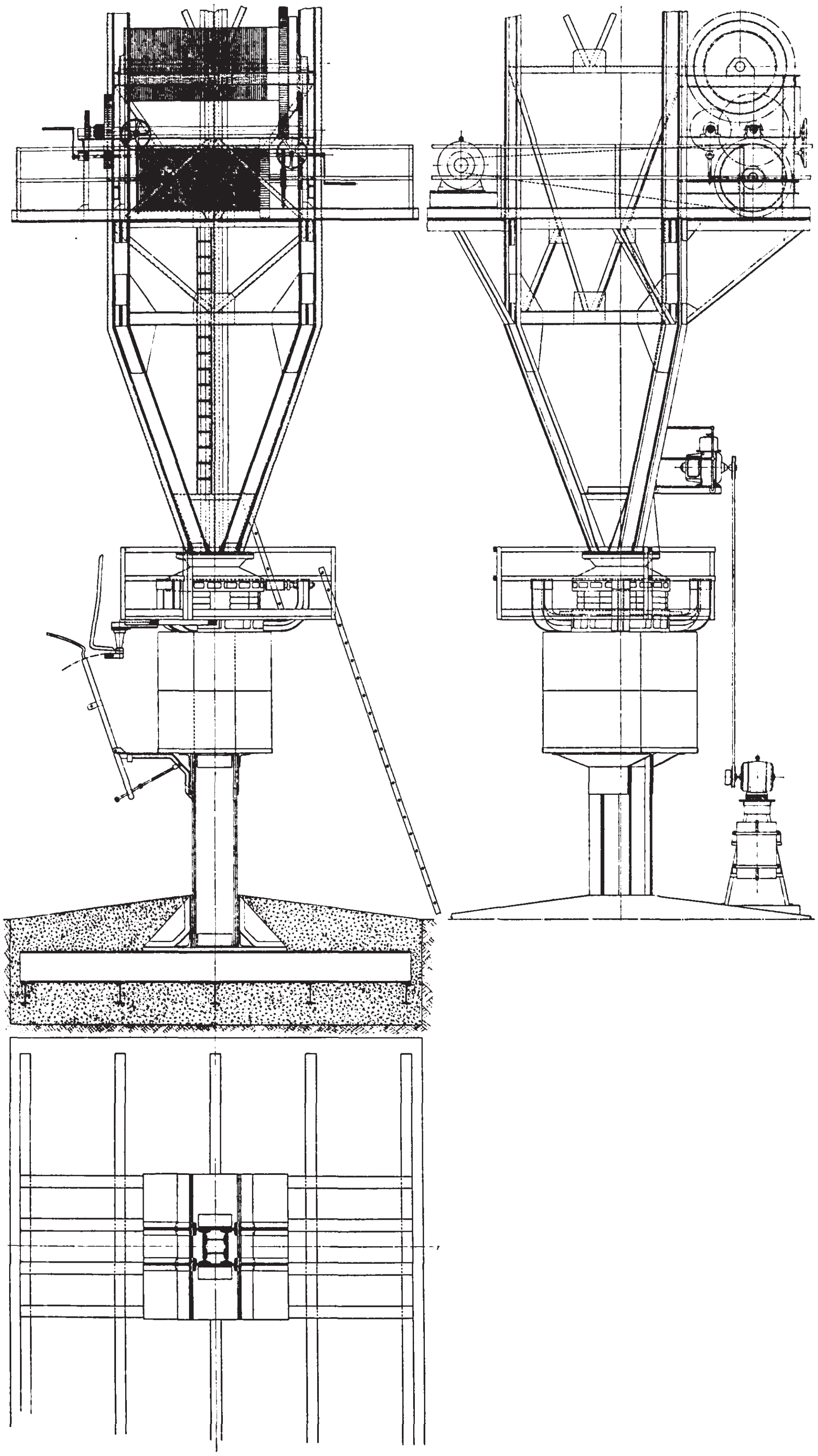

Fig. 22.—Base of mast.

the resultant vertical load on the base of the mast is 400 tons.

The foundations of the mast consist of a reinforced concrete block 20 ft. × 20 ft. × 6 ft. The reinforcement consists of one row of steel joists 18 in. × 7 in. × 75 lb. and a second row of steel joists of 12 in. × 6 in. × 44 lb. placed at right angles to the first row: the steel joists are bolted together and the steel supporting stanchion is bolted to the upper row of joists (Fig. 22).

The maximum load on the earth surface is 1 ton per sq. ft.

Borings were taken at mast positions to depths of about 25 ft. and averaged 1 ft. of soil, 3 ft. to 8 ft. of yellow loam and 12 ft. of soft blue clay, below which was stiff blue clay. In one case only running sand was encountered and the foundations were carried below this to the blue clay.

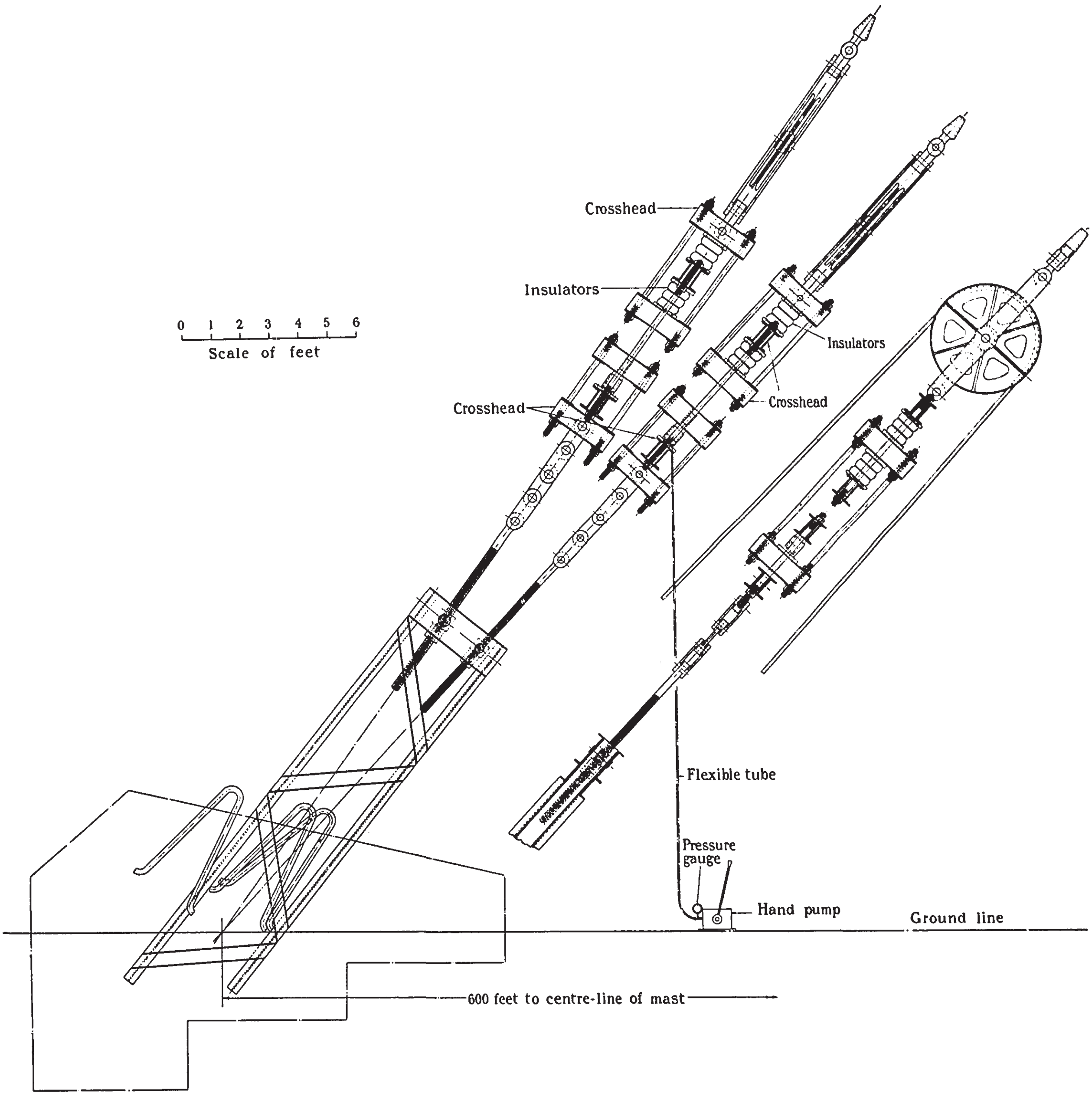

FIG. 23.—Stay arrangement and anchorage.

INSULATION OF THE MASTS.

Two considerations arose in determining the method to be adopted in insulating the masts :—

(1) The choice of a dielectric capable of withstanding a high voltage at high frequency and a considerable compressive load.

(2) Arranging the insulating medium so that the capacity of mast to earth was as low as possible.

The solution arrived at is indicated in Fig. 22. The insulation is primarily provided by 12 columns of porcelain insulators arranged three in each column and placed between steel castings immediately below the pivoted joint. These insulators comply with the specified conditions of withstanding a high-frequency voltage of 25 000 (R.M.S.) at 50 000 cycles per sec. for 6 hours without overheating or breaking, the insulators having first been immersed in water for 2 hours. They were tested mechanically to a compression load of 270 tons, corresponding to a factor of safety of 6.

Each insulator is 9 inches in diameter and $3\frac{1}{2}$ in. thick, with a recessed hole in each face $2\frac{1}{2}$ in. diameter and 1 in. deep.

To ensure uniform distribution of stress between the columns all insulators have ground faces and those in each column were cemented together by a thin layer of Portland cement.

Wooden blocks were used in the place of the insulators during the erection of the masts. To insert the insulators, the mast was raised on hydraulic jacks, the wooden blocks were removed and the columns of insulators inserted with a thin layer of cement at the bottom. The mast was then lowered on the insulators, but the full load was not taken off the jacks until the cement had properly set.

It will be noted (see Fig. 22) that the arrangement of the insulators permits of the insertion of 3 hydraulic jacks to raise the mast and replace any damaged or faulty insulators as required.

The stays are insulated at the base only. The same type of insulator is used as for the mast base, the method of mounting being indicated in Fig. 23. The insulators are in compression, the top column taking the load and the bottom acting as steadying insulators. A hydraulic press is incorporated in the stay-rope attachmen and can be connected to a hydraulic pump and gauge on the ground and used to measure directly the tension of the stay.

The stays are of parallel strand construction and were made on the site. The maximum tensions imposed on the stays under full wind load vary from 30·5 to 37·6 tons in the different stays, the top and bottom sets carrying rather higher loads than the intermediate, and two sizes of stay ropes were adopted. The larger is composed of 151 wires of No. 10 S.W.G. having an area of 1·918 sq. in. and a circumference of $5\frac{1}{2}$ in., and the smaller of 103 No. 10 S.W.G. and 6 No. 8 S.W.G. The factor of safety specified for the stay ropes was 4.

The individual wires of No. 10 S.W.G. have an extension, within the elastic limit, of 0·5 per cent under a stress of 57·7 tons per sq. in., and a breaking load of 3 050 lb.

The aggregate breaking load of the larger ropes, assuming uniform distribution on all the wires, would be about 205 tons. Short lengths of rope with sockets attached were tested in connection with experiments carried out to determine the best type of socket, and the ultimate strength of the rope was greater than 125 tons, the limit of the machine available for the tests. This type of stay has a great advantage over the usual small wire stranded variety in possessing a smaller extension under load. The parallel-strand type has an extension very little in excess of that of the individual wires and, for the longest stay in use on the Rugby masts, this, under maximum load, does not exceed 17 in. irrespective of variations due to temperature, or, allowing for a temperature-rise of 50 deg. F., 21 in. The best results obtained on stranded ropes of special construction and under similar conditions would be equivalent to 35 in. extension for the longest stay at Rugby.

The advantage of the use of the parallel-strand construction is thus evident in limiting the heel of the mast under conditions of load. A further advantage of the use of parallel-wire ropes is that a more exact determination of stay stresses is possible. The masts were manufactured and erected by Messrs. Head Wrightson and Co.

Switches of substantial design are provided for earthing the masts when access to them is required and also for enabling transmission to be carried out at full power with the masts earthed. A spark-gap is also associated

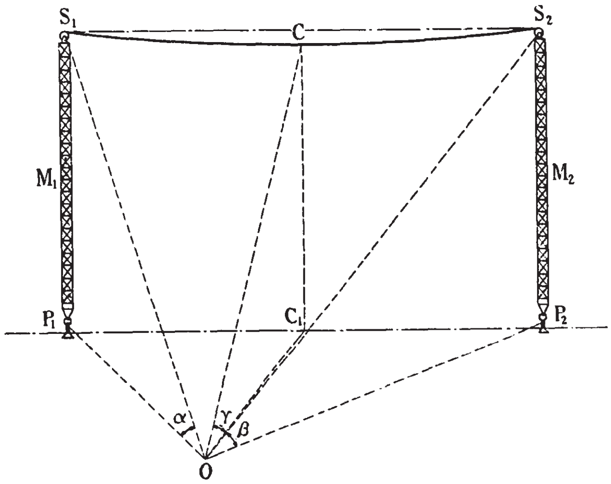

FIG. 24.—Method of load-testing masts.

with the switch as a protective device against abnormal voltages on the masts or aerial.

In order to test the masts with the specified horizontal pull of 10 tons applied at the top, a steel rope was suspended between two masts and hoisted by means of the permanent mast winches until the required tension was reached. Fig. 24 illustrates the method employed. P_1 and P_2 are the vertical projections on the ground of the ends of the rope S_1, S_2, suspended between the masts M_1 and M_2. A theodolite was fixed at O such that the length $OP_1 = OP_2$. The angles of elevation α and β of S_1 and S_2 were measured accurately, and also the angle of elevation γ of the lowest point C of the steel cable. It was then a simple matter to measure the angle P_2OC, in the horizontal plane, C_1 being the vertical projection of C. Also the angle C_1P_2O = angle C_1P_1O being known, and the length OP_2 having been accurately measured, the distance OC_1 was calculated. Thus it was possible to calculate the values of $S_1P_1 = OP_1 \tan \alpha$, $CC_1 = OC_1 \tan \gamma$, and $S_2P_2 = OP_2 \tan \beta$, and so obtain the dip d of the cable. The mass per foot of the steel rope, w,

and l, the distance S_1S_2, being known, the horizontal tension

$$T = \frac{wl^2}{8d}$$

was obtained.

A check on the aerial dip was also made by the same methods. The current taken by the electric motors of the winches, however, was found to give readings consistent with the value of the tension in the aerial suspending halyards and, during the erection of the aerial, reliance was placed upon these readings.

Mast and Aerial System.

The mast and aerial system are arranged so that two separate aerials of different capacities may be used or alternatively the two combined to form one larger aerial (Fig. 1). Two of the masts, spaced symmetrically with regard to the station buildings and 1 320 ft. apart, are common to both aerial systems. The larger of the two aerials is the telegraph aerial and is supported on 8 masts arranged to form an elongated octagonal figure in plan, with sides of 1 320 ft., but with opposite sides on axes at right angles at distances apart of 880 yards and 1 210 yards.

The smaller aerial is supported on 6 masts with the same spacing but forming an aerial with two open arms. This arrangement is designed to permit of the addition of four more masts if necessary, for which purpose sufficient ground is available.

Each aerial system is fed by a lead-up connected to two separate feeders, one attached to each of the masts nearest to the station. When using the whole system as one aerial the leads-up to the two separate aerials are connected together by an internal cable running the whole length of the inductance room.

The aerial insulators are of the porcelain-rod tension type, weighing 6½ cwt. and are shown in Fig. 25. The specified testing pressure which the insulators had to withstand was 120 000 volts at a frequency of 50 000 cycles per second.

Each porcelain tube of the aerial insulator was tested to a load of 10 tons. The complete insulator will thus withstand a pull of over 20 tons. Electrical tests made previous to erection showed that 200 000 volts at 50 000 cycles per second could be applied across the ends without damage. The insulators were made by Messrs. Bullers, Ltd.

Spider spreaders of tubular steel, 12 ft. in diameter, and spaced 140 ft. apart, are used to support the eight 7/14 S.W.G. silicon-bronze wires that form the cage aerial. In order to reduce the dip of the aerial, it was essential to design spreaders having small mass without undue sacrifice of strength. The type decided upon, as best meeting these requirements, is shown in Fig. 26. The split hubs of each spreader are tightly clamped to a central steel supporting cable. All radial arms and circumferential ties are composed of weldless carbon steel, containing about 0·5 per cent of carbon, with a yield point of 30 tons per sq. in. and an ultimate breaking stress of 40 tons per sq. in. In spite of their light structure the spreaders have withstood the severest gales without apparent damage. At each mast the aerial insulator is attached to the steel wire cable at the junction of two spans of the cage aerial, and the aerial is held in space well away from the metal masts.

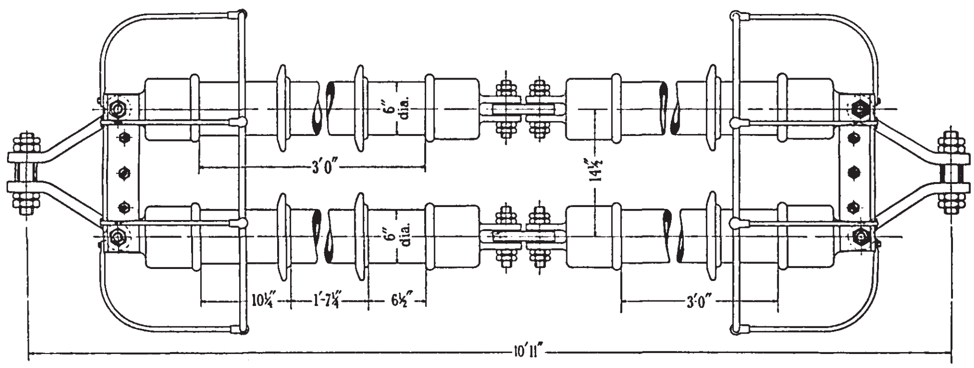

Fig. 25.—Aerial insulator. Scale ⅜ in. = 1 foot.

The two 8-wire feeders are formed on spreaders 6 in. diameter spaced 20 ft. apart. They meet at a point about 400 ft. from the building and are joined to form a single 16-wire lead-up on 6-in. spreaders. The tension of the lead-up wires is taken by six porcelain tubes, similar to those used in the main aerial insulators, suspended on a steel structure near to the building. The six tubes are arranged to form three arms 120° apart, each arm comprising two tubes in series. From these strain insulators, the lead-up wires pass through a copper tube about 19 ft. long that bridges the space between these insulators and the transmission building. At the building the tube carrying the lead-up wires passes through the middle of a double conical porcelain insulator fixed at the centre of a glass plate, 7 ft. square, and the lead-up wires then pass from the tube to the aerial tuning inductance.

In order to avoid either the overloading of the mast or the breaking down of the aerial, the steel rope supporting the aerial insulators passes down the centre of the mast and is attached to a drum fitted with a slipping friction brake so adjusted that the rope is slackened when the load exceeds 10 tons.

The earth system on the telegraph site consists of

copper wire, 100 lb. per mile, buried a few inches below ground. The earth follows the plan of the aerial and extends 800 ft. on either side of the vertical projection of the aerial on the ground, as shown in Fig. 27. Near the buildings the wires leave the ground and converge upon the transmitting room in a fan arrangement.

An insulated counterpoise has been erected under the smaller aerial at an average distance of about 16 ft. from the ground. The counterpoise follows generally the earth system in arrangement, except that the spacing between individual wires is not uniform but varies from 40 ft. immediately below the cage aerial to 80 ft. at the edges.

Observations have been made on the effectiveness of the insulation at the base of the mast by comparative measurements of the aerial resistance and the effective height with the masts insulated and connected to earth.

These observations show that the ratio of the effective height of the aerial with the masts insulated, to the effective height with the masts earthed, is 1·22. The effective height with masts insulated as deduced from measurements made at Wroughton near Swindon is approximately 185 m (607 ft.). The mean geometric height of the top of the aerial at Rugby is 820 ft. — 45 ft. (average dip of aerial) = 775 ft.

The effective height with the mast insulated is therefore 607/775 = 0·785 of the mean geometric height, or 607/820 = 0·74 of the mast height.

Fig. 28 gives the resistances of the aerial with masts insulated and masts earthed respectively. At 19 000 m wave-length the aerial resistances with the masts insulated is 0·7 ohm, and the aerial resistance with the masts earthed is 0·55 ohm.

Fig. 29 shows that the use of inefficient insulators for the masts practically doubles the aerial resistance. Such inefficient insulation is obtained when the porcelain insulators only are short-circuited and the granite blocks alone are used as insulators.

The larger telegraph aerial constants with the mast insulated are: wave-length 7 930 m, capacity 0·0334 μF, and equivalent inductance 530 μH.

To enable overhauls and examination of masts to be made, it is desirable to be able to transmit with a particular mast earthed, as work on an insulated mast is impossible during transmission. The curves in Fig. 30 indicate the effect on the larger telegraph aerial resistance of earthing either No. 1 mast (which is nearest to the station) or No. 6 mast (which is at the end of the aerial).

The d.c. insulation resistance of a mast to earth, including all stay insulators, varies between 1·5 and 3 megohms according to weather conditions.

The insulation resistance of the whole aerial to earth with masts insulated is 8 megohms.

The resistance of each granite block is approximately 20 000 ohms, but the value steadily rises as the granite slowly dries out. The effect of the dielectric current in the granite is to drive out moisture gradually from the interior. This action, combined with absorption by

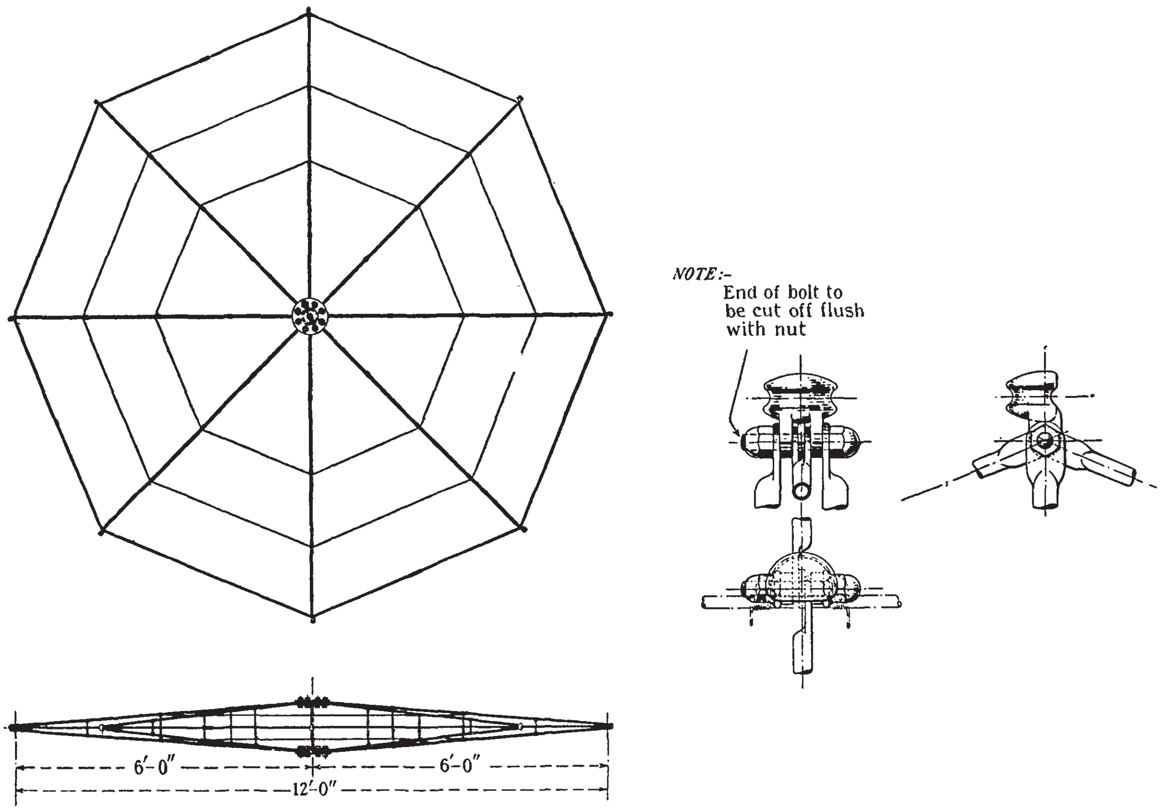

FIG. 26.—Aerial spreader.

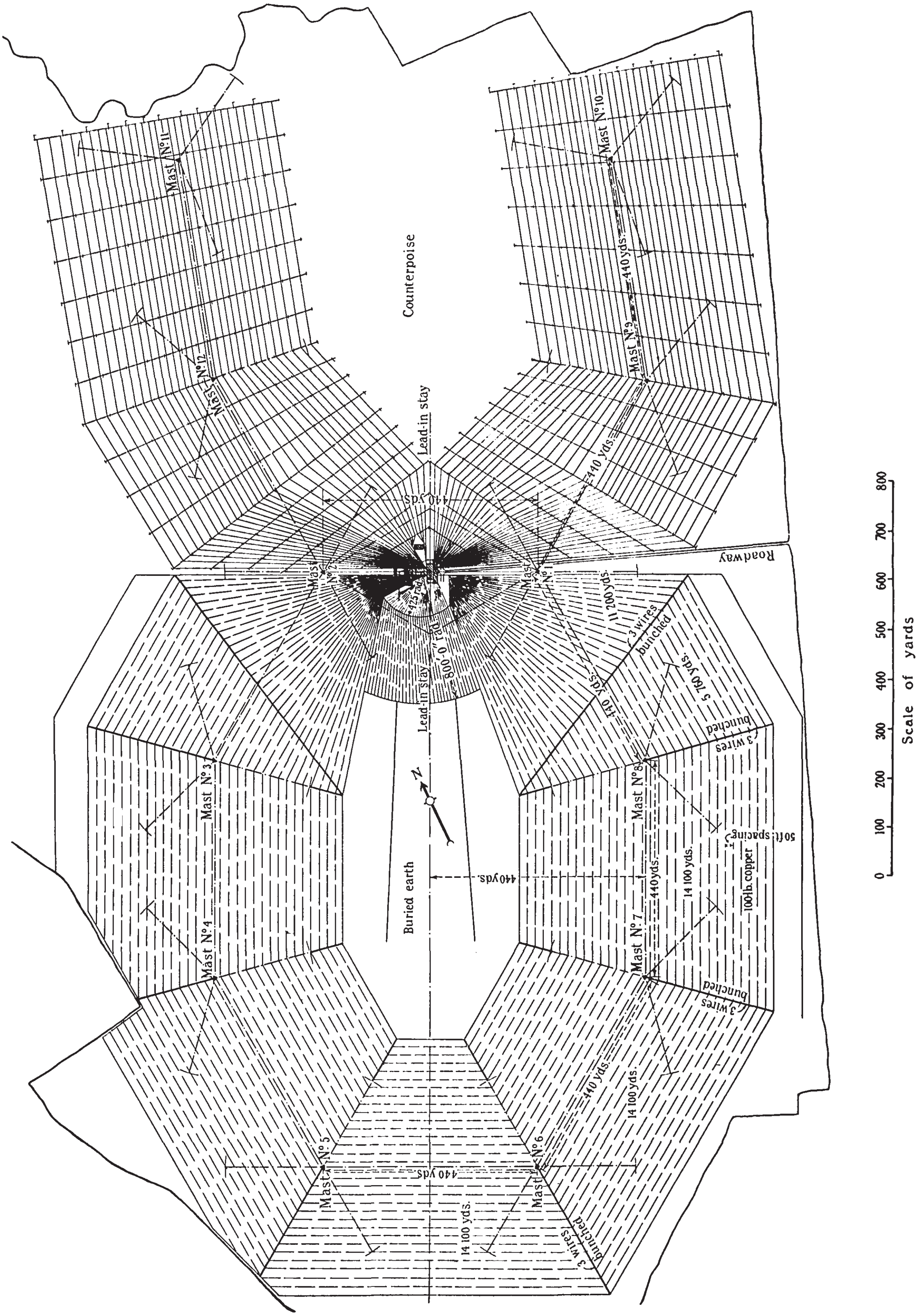

FIG. 27.—Earth system.

the atmosphere in the spring and summer, will raise the insulation to a maximum value and the granite blocks will then be completely coated with bitumastic solution to retain them in a dry state. Bitumastic solution has been tried experimentally for this purpose

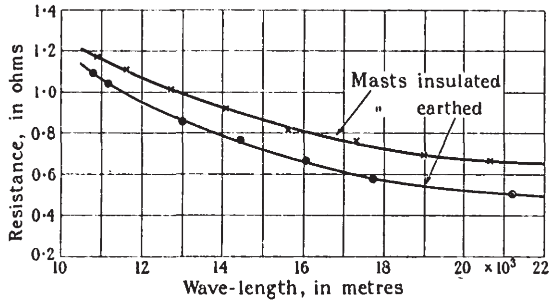

FIG. 28.—Curves of aerial resistance with masts insulated and earthed, respectively.

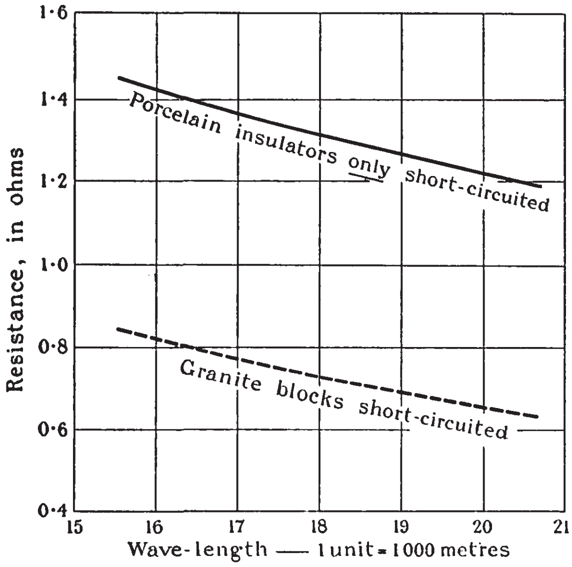

FIG. 29.—Curves of 8-mast aerial resistance with insulators partly short-circuited.

Tests taken first week in November, 1925. Ohmic resistance of each granite block = 12 000 ohms. Ohmic resistance of porcelain insulators under each mast = 3 megohms.

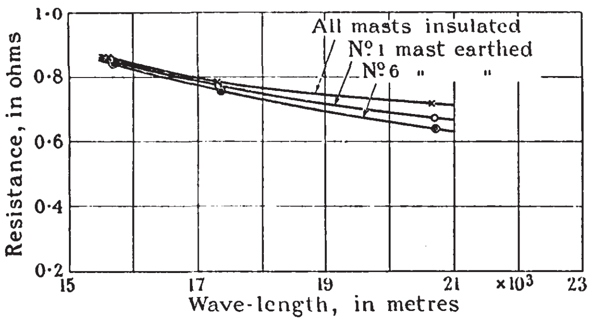

FIG. 30.—Curves of aerial resistance, earthing separate masts.

and proved to be satisfactory. The method outlined for slow drying under working conditions was decided upon as the results of tests made on granite specimens and in order to obviate the risk of moisture remaining in the granite if the blocks were coated with bitumastic solution before erection.

The voltage-drop across the mast insulators was found to be 12 000 volts and the drop across the stay insulators 12 300 volts with an aerial voltage of approximately 165 000, corresponding to an aerial current of 550 amperes.

Curves of the resistance of the smaller telegraph (telephone) aerial and counterpoise are given in Fig. 31. In order to obtain information, measurements were taken both before and after the far ends of all the wires of each arm of the counterpoise were connected together. The smaller telegraph (telephone) aerial constants are: wave-length 4 850 m, capacity 0·0164 μF, and equivalent inductance 394 μH.

COOLING POND.

A stream running through the site is utilized to supply the cooling water, and a ferro-concrete cooling pond capable of storing 500 000 gallons of water was constructed by direct labour.

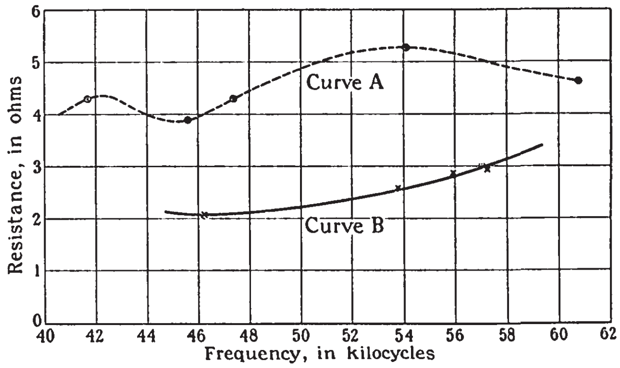

FIG. 31.—Resistance curves of telephony aerial.

Curve B shows the effect of joining together the ends of all the wires of each arm of the counterpoise. Counterpoise insulated in each case. Insulation resistance about 60 000 ohms.

GENERAL RESULTS OBTAINED TO DATE.

The following schedule gives two typical series of measured values of the more important quantities when working on one portion of the aerial only, viz. that having a capacity of 0·033 μF.

Number of power units in use	3	3
Total number of valves in power units	54	54
Aerial circuit — Current	550 amps.	600 amps.
Aerial circuit — Power	257 kW	306 kW
Primary circuit current	275 amps.	300 amps.
Coefficient of coupling to aerial	0·015	0·015
Efficiency of coupled circuit	97½ %	97½ %
D.C. Input — Voltage	5 820 volts	6 780 volts
D.C. Input — Current	61 amps.	64 amps.
D.C. Input — Power	355 kW	434 kW
Filament power	48 kW	48 kW
Efficiency of transmitter — Excluding filament	72 %	71 %
Efficiency of transmitter — Including filament	64 %	64 %
Voltage on antenna	165 000 volts	180 000 volts

These figures are for about two-thirds power of the station, the present limitation being the fact that only a portion of the main aerial is available, which portion is already being used at antenna voltages in excess of 165 000. With this power, however, the station has been proved to have a world-wide range and only the collection and scrutiny of data over a long period will show to what extent, if any, an increase of power is necessary for a *continuous* world-wide service. From the experience already gained it can be predicted that, if it is proved to be necessary, 3 power units using a d.c. supply of about 9 000 volts will be able to give an antenna current of the order of 750 amperes in the larger antenna of $0 \cdot 045\ \mu F$, with an increased overall efficiency.

It is interesting to note that during the several months that the telegraph station has now been testing and working commercially with type D circuit, not a single complaint has been received in regard to interference with broadcast or other reception by harmonics from the telegraph transmissions, and, moreover, broadcasting stations have been received, without interference, on the site under the aerial.

Experimental Telephony Installation.

The experimental telephony installation is smaller than the telegraphy installation and works with the smaller aerial. It utilizes the American Telephone and Telegraph Co.'s "single side band" system described by the late Dr. H. W. Nichols.* The modulating and filtering circuits and the valve amplifying panels were made and installed by the Western Electric Co., Ltd., in co-operation with the American Telephone and Telegraph Co.

* *Journal I.E.E.*, 1923, vol. 61, p. 812.

From the 31st January to the present time, a period which covers the best radio transmission conditions in this country, experimental week-end tests show that good speech is received in New York during most hours of the day when using an aerial current of about 185 amperes. This installation may form the subject of a separate paper when reliable data has been collected over the period of bad atmospheric conditions.

In addition, two other installations to work with smaller aerials supported on the existing masts are being provided. One will be a medium-wave 50-kW valve set and the other a short-wave 15-kW valve set.

Conclusion.

As liaison member between the Wireless Telegraphy Commission and the Post Office the author would like to remark on the cordial collaboration which existed between the Commission and his engineers throughout the progress of the work, and in conclusion he desires to acknowledge the valuable help received in writing this paper from the Post Office Engineers directly responsible for the various sections of the work, namely Mr. A. J. Gill on the power plant, Mr. R. V. Hansford on the wireless plant, and Col. A. S. Angwin and Mr. T. Walmsley on the masts, aerials and external plant.

Discussion before the Wireless Section, 14 April, 1926.

Sir Guy Wrightson: A description of the masts and the various difficulties we experienced in erecting them was the subject of a recent paper read before the Institution of Civil Engineers by Col. Angwin and Mr. Walmsley. In that paper I think there was only one interesting point omitted, viz. the weather factor. This work took place during an extremely wet and windy season and we were very lucky in having not a single accident in working at those great heights in very windy weather.

Mr. C. F. Elwell: The Post Office engineers have advanced valve practice to such an extent that no other valve station has anything like the power of the Rugby station. In view of the possibility of the erection of further stations of this type and power there are two points to which I should like to draw attention. The first is the question of the number of masts. Is it necessary to erect so many? There are no engineering difficulties in the way of erecting even higher masts, nor are there any difficulties in the way of providing for much greater aerial pulls—for example, 30 tons. In this case probably the masts could have been spaced double the distance apart. This is only an idea for the future. The question of economics has to be studied, but I believe that probably half the masts could have been erected with each one a little higher; this would have compensated for aerial sag, and have enabled a little money to be saved. The other point is the multiplicity of small valves. Personally I believe in the future of single units. Such a unit would no doubt be of a type which would have its own pumping outfit. We are at present in the possession of very little data as to the maintenance of small valves. In the case of a single valve I think it is quite possible to renew its filaments and generally keep it in order at the cost of certain spare parts.

Mr. P. P. Eckersley: I think that any criticism that might be put forward falls to the ground entirely when it is realized that even as far back as 5 years ago the Commission were bold enough to back their preference for valve work, which was then considered, by even the greatest enthusiasts, somewhat dubious for high-power stations. Finally, they have applied real engineering practice and technology to the production of high-frequency currents. I think they are to be congratulated on this account above all others. The tuning-fork drive is, I think, a unique advancement, as everyone must admit that the great aim of the future, both in broadcasting and in telegraphy, must be towards the maintenance of a constant wave-length. It may be of interest to mention that the British Broadcasting Co. also has had some experience of producing harmonics from tuning-forks and using them as independent drives. Starting with a frequency of something like 890 periods per sec., we have been able successfully to drive a particular station at a frequency

of nearly 1 million. Referring to Mr. Elwell's remarks on valves, I suggest that the Post Office engineers have taken the safe course. I should like to ask the author whether the economic gain resulting from insulating the masts could not also have been obtained by employing a somewhat greater power. Apparently the insulating of the masts was an expensive and difficult engineering task involving considerable experimental work, and it would be interesting to hear whether the author is of the opinion that the same result might have been obtained by omitting the mast insulators and providing a larger aerial current to compensate for any reduction of energy actually radiated. We shall all await with great interest the development of the transatlantic telephone experiments.

Mr. G. Shearing: The Rugby radio station represents the most ambitious undertaking in thermionic valve wireless-telegraph transmission up to the present. Its erection must have been a problem of extreme interest, for the task of building complete a high-power valve transmitter such as this, with practically no limitations, is one which comes the way of few radio engineers. The high oscillatory power obtained by the use of thermionic valves is, I venture to think, very gratifying to all who have been engaged in the experimental development of high-power valves. In view of the application of shorter wave-lengths below 100 m at the present time to long-range transmission, and the remarkable results one can obtain with relatively small power supply, it is not easy to say whether the Rugby station is the climax of high-power long-wave valve transmitters; and the trend of wireless telegraph development in the next few years will be a matter of great interest to us all. With regard to the power supply from the substation at Rugby, I should like to know if the line drop to the radio station is negligible or whether the automatic regulators compensate for line drop at varying loads. It would be of interest if the author could give us the load characteristics of the high-tension d.c. generators. Concerning the adoption of motor-generator sets for the high-tension supply by the Wireless Telegraphy Commission in 1922, I am wondering if the author is still of the same opinion, as thermionic rectifying valves can be obtained of good efficiency and on the whole of greater reliability than transmitting valves of the same anode rating. Possibly some economy might result from the adoption of thermionic apparatus for both transmitter and high-tension supply. On the other hand, there is the question of the interposition of the inertia of a mechanical link between the supply undertaking and radio apparatus for the high-tension generator to reduce fluctuation of the supply power during signalling, as opposed to a purely electrical link for the static high-tension transformer and thermionic valve rectifier unit, unless an a.c. generator and motor is introduced also for the h.t. transformer supply. With regard to the adoption of a frequency of 100 for the valve filaments, would not a higher frequency, say of the order of 250, have been better when introducing the motor plant? This would reduce considerably any cyclic temperature fluctuation of the valve filaments as compared with that produced by the small change in frequency from 50 to 100. With reference to the transmitting valves, the designed power dissipation per valve from the figures on page 120 is of the order of 460 kW, or about 8·5 kW per valve, and the test-figures on page 138 correspond to an average anode dissipation of nearly 2·4 kW per valve during marking (I assume the static dissipation is less than this; perhaps the author will say what is its value), so that the valves at present are being operated at a fairly conservative anode power rating as compared with the continuous rating of 10 kW of which each valve is capable. In this connection, is it easy to arrange for the valves to share the load equally? If not, is it possible to correct by filament adjustment alone or are other adjustments necessary; also, have the valves any repair value after breakdown? The inductively coupled circuit of type A (Fig. 16) is undoubtedly inferior to the capacity-coupled arrangements described in the same figure, but for the cases where rapid wave-change over a wide range renders its use desirable, a great reduction of harmonic interference can be obtained by the insertion of a rejector type of circuit between the anode tapping and earth. This is, of course, equivalent in effect to the introduction of a capacity circuit to earth to provide an easy path for the harmonics. The harmonics generated on the Rugby wave-length which may cause interference in general to broadcasting apart from Daventry, are those around the 40th harmonic of the fundamental, and it would be of interest to know whether any radiation has been observed on the lower harmonics such as the 2nd, 3rd, etc. It would also be interesting to obtain an oscillograph curve showing the change of the anode current through the valves during signalling, for comparison with the curve of rectified aerial current given in Fig. 20 of the paper.

Mr. R. N. Vyvyan: The Marconi Co. have been designing high-power stations for Imperial communication on long wave-lengths for a great many years. Actually we designed a station only a short time ago on the valve system to give 875 amperes in an aerial supported by masts approximately as high as those at Rugby. That station was not completed, however, owing to the introduction of the short-wave beam system. I think it is certain that the Rugby station is the last word in high-power wireless stations, in two senses. It is excellently designed in every respect and, in my opinion, reflects great credit on the Post Office engineers, but I do not think that any more super high-power stations will be built, since long-distance communication will, I believe, in future be carried out only by the short-wave beam system. That is also the opinion of my company, but we shall know in a very few weeks whether that opinion is sound or not.

Mr. W. T. Gibson: The author mentions that distilled water is used for cooling the valves. He points out one advantage of this, and I propose to give another. The point he mentions is the very high resistance obtained with the water, giving a leakage current of only 20 mA at 10 000 volts, or 200 watts power loss. With ordinary domestic water the leak would probably be 20 or 30 times as great. That does not matter much in small stations utilizing one or two valves, but with a station of the size of Rugby it becomes very important and there would probably be a loss of 4 or 5 kW in the

hose pipe. The other interesting point in connection with distilled water is that there is no deposit in the anode, whereas it is a matter of experience with ordinary commercial water that quite a considerable deposit is formed on the anode at places where it gets warm. That would become very serious and might create serious maintenance problems in removing the deposit at frequent intervals. The layer is a good insulator and a very bad conductor of heat, steam is formed underneath the anode and possibly overheating of the anode occurs. I agree with Mr. Elwell that in the future there will be a development in the size of valves, but I do not agree with him that the demountable valve is the valve of the future. The great thing is to have a valve of absolutely stable characteristics, and I believe that these are extraordinarily difficult to obtain with a valve that is permanently connected with the pumps. There are always slight traces of gas and the pressure is always fluctuating slightly, and that presents great difficulties in operating a large station. Those difficulties, I think, outweigh any advantage in being able to take the valve apart and re-assemble it.

Prof. J. K. Catterson-Smith : I presume that the aerial constants given on pages 136 and 138 are the fundamental natural wave-length and the equivalent capacity and inductance at this wave-length. The equivalent inductance of the smaller aerial, given in the advance copies of the paper as 994 μH, appears to be wrong. Should not it be 394 μH ? There is apt to be some confusion as to the exact meaning of such aerial constants, and therefore it might be helpful to state that for these aerials the electrostatic capacities are $0 \cdot 0524\ \mu$F and $0 \cdot 0258\ \mu$F, and the static inductances 832 μH and 618 μH, for the larger and smaller aerials respectively. I notice that the resistance of the larger aerial is plotted, in Fig. 28, for wave-lengths down to 10 800 m, and I should like to know whether these observations were made with lower values of the aerial tuning inductance than the minimum of 900 μH given in the paper. In the case of this aerial, for which the equivalent inductance is stated to be 530 μH and the capacity $0 \cdot 0334\ \mu$F, the effective inductance is $(1/\sqrt{2}) \times 530 = 375\ \mu$H, and the effective capacity is $\sqrt{2} \times 0 \cdot 0334 = 0 \cdot 0471\ \mu$F, so that the range over which the aerial can be tuned with the 900 to 4 000 μH aerial tuning inductance, and neglecting the coupling coil, should be :—

$$\text{from } \lambda = 59 \cdot 6 \sqrt{[(375 + 900)\ 47 \cdot 1]} = 14\,500 \text{ m}$$
$$\text{to } \lambda = 59 \cdot 6 \sqrt{[(375 + 4\,000)\ 47 \cdot 1]} = 27\,000 \text{ m}.$$

Although efficiencies for the transmitting apparatus are given on page 138, I find no statement of the aerial efficiency, which is an equally important matter. Adopting the value of the effective height given on page 136 (viz. $183 \cdot 5$ m) the radiation resistance of the larger aerial works out as $0 \cdot 158$ ohm at 18 350-m wave-length, for which Fig. 28 gives the measured resistance as $0 \cdot 72$ ohm with the masts insulated. The aerial efficiency is then $0 \cdot 158/0 \cdot 72$, or 22 per cent, a figure which does not compare too favourably with published values of the efficiency of multiple-feeder aerials. I suppose that aerials of the latter type were considered before the final decision was made to adopt the present form of aerial at Rugby. I should like to take this opportunity of suggesting the sending of special test-signals similar to the "U R S I" transmissions, in order that distant measurements could be made over considerable periods. Such observations would, I am sure, be undertaken by a number of laboratories and the results, when collected, would probably afford matter of interest on this class of transmission. We make daily observations of signal strength at Bangalore and would welcome the possibility of recording and measuring the field strength of systematic signals from Rugby.

Dr. W. H. Eccles (*communicated*) : I speak as Vice-Chairman of the Wireless Telegraphy Commission which was instructed by the Government to prepare the general design of the Rugby wireless station and to advise during erection. The author was a member of the Commission and also head of the body of engineers who installed the plant. It is largely due to him that the co-operation between those responsible for the general design and those responsible for the construction was so perfectly cordial. I think it would be hard to find an example of a very big job involving innumerable departures from traditional methods in which the team work has been so good. This has helped to ensure success ; a success which could not have been achieved without the aid of the able staff which the author has gathered round him at the Post Office. This staff has been responsible, for example, for the development of the method of controlling the wave-length by a tuning-fork, for the design of the valve panels and safety devices, for the calculation of the unusual form of intermediate circuit and tuning coils, for the erection of the very unusual type of antenna, and for the testing of electrical materials by new methods. But the best testimonial to the efficient work of the erecting engineers is the fact that the station has given magnificent performances during its tests and that its erection was completed without any failure, fault or accident. As may be imagined, the volume of business involved in the purchase of the plant and materials for the station was enormous ; and although this side of the work is not described in the paper, I think I may be permitted to say that the author shouldered most of the burden and that the estimates were very closely in accord with the final expenditure.

Mr. E. H. Shaughnessy (*in reply*) : Mr. Elwell raises the question of utilizing a smaller number of higher masts. Calculations made at the time the estimate was prepared indicated that the number, height and aerial-pull chosen were the reasonable constructional and economical limits. It cannot be said that a valve with a 10-kW output is a small valve ; no reliable larger-powered valve was commercially available at the time the station was designed. The Post Office has very little data as to the maintenance and repair of small valves, and no data at all regarding valves with over 20-kW output. Attention is drawn to sub-paragraph 3 (*b*) in the section headed "Considerations in regard to the size of power units."

I am glad to hear from Mr. Eckersley that the British Broadcasting Company is following the Post Office example of producing constant wave-length from a tuning-fork. With regard to using additional valves

and increased aerial power instead of increasing the effective height of the aerial, owing to corona and voltage limits on the aerial and aerial insulators, the matter is not so simple when dealing with such powers as that used at Rugby.

The various points raised by Mr. Shearing were all considered in the design stage of the Rugby station. The use of 100 cycles for the filament supply was adopted, not for the sake of changing frequency but in order to simplify regulation by the use of a motor-generator and Tirrill regulator. The cyclic temperature-variation effect is overcome by balancing the valve filaments in use over the three phases, as explained in the paper. The choice of 100 cycles was made in order to obtain a standard frequency-changing machine which could be delivered quickly. The rating of the valves is in terms of the anode voltage, output and dissipation, each valve being limited to a maximum output or dissipation of 10 kW. Thus it is not permissible to operate the valves beyond the rated anode voltage, output or dissipation. The figure of 1 000 kW quoted is the machine rating; the input to the power units for 540 kW output when working at 72 per cent efficiency would be considerably below this figure. The present static dissipation on "space" is 1 kW per valve. Provided that the precautions specified (page 124) for the operation of valves in parallel are adopted, the valves share the load equally. It will be appreciated that Rugby is essentially a fixed-wave-length station and, in consequence, the time required to change wave-length does not arise. For this reason a coupled circuit was provided which gives a much more efficient anti-interference arrangement than rejector circuits, etc. Observations so far made on harmonic radiation show that there is no radiation on the lower harmonics. Additional oscillograms showing the rise and fall of the various currents and voltages during keying will probably be published at a later date.

Mr. Vyvyan will be the first to recognize the difference between designing a station to give 875 amperes in the aerial and erecting a station that actually has that aerial current. The absolute need for a high-power station in this country which has a simultaneous broadcasting Empire-wide range has been met by the erection of the Rugby radio station. I think it is too early to conclude that no more high-power stations will be built. Our experience of low-power short-wave stations is that they form valuable adjuncts to high-power stations, being able to work for a limited number of hours per day but not regularly at the same time or for the same periods. As beam stations are directional it would require a large number of these to cover Empire broadcasting, and as no beam station has yet been completed or tested I am quite unable to form any opinion as to its superiority or otherwise over ordinary short-wave stations.

As Mr. Gibson points out, it was with a view to avoiding deposit on the anodes that distilled water was adopted for valve cooling at Rugby. The need for this is emphasized when such a large number of valves are being run in parallel.

I have to thank Dr. Eccles for his generous contribution to the discussion.

With reference to Prof. Catterson-Smith's communication, it is, of course, very difficult to quote definite figures of capacity and inductance for a given aerial without making a large number of reservations as regards frequency, etc., on account of the distributed nature of the capacity and inductance. For practical purposes, the values, C_a, L_a, required are those which will give approximately correct results for a reasonable working range of frequency for the calculation of the wave-length with varying values of loading inductance, L_1, when using the formula $\lambda = 1\,887\sqrt{[C_a(L_a + L_1)]}$. The figures quoted in the paper are the values of C_a, L_a, for the two aerials as defined above, and the figure of 994 μH in the advance copies of the paper was a typographical error for 394 μH, as pointed out by Prof. Catterson-Smith, and has since been corrected The measurement of the aerial resistance was carried out by means of a specially designed measuring-set which did not utilize the aerial tuning inductance. Multiple-feeder aerials were considered before the final design of the Rugby aerial was adopted. The aerial efficiency is of the order quoted by Prof. Catterson-Smith, and I think that he will find that this does not compare unfavourably with the efficiency of multi-tuned aerials at wave-lengths of the order of the high wave-length quoted by him and used at Rugby.

South Midland Centre, at Birmingham, 28 April, 1926.

Mr. G. Rogers: The author remarked that the ether is becoming overcrowded, with the result that interference takes place between the many high-power stations now working. I do not really think that he means this. It may seem to be so with our present knowledge of the ether, and the means of tuning-in to different wave-lengths. It is inconceivable, however, that the saturation point has been even nearly reached. As the ether is apparently illimitable and pervades all space, its capacity to transmit energy may also prove illimitable. In fact, I venture to suggest that means will be found later to obviate any interference. Also it is quite within the range of possibilities that, in the future, many hundreds of thousands of kilowatts of power will be transmitted through the ether without the saturation point being reached. Was any provision made to protect the huge steel masts and the aerial from lightning? One is familiar with the enormous destructive forces that can be liberated and as, apparently, no protection whatever from lightning has been provided, there would seem to be a possibility that the porcelain base and the granite block at the bottom of each of the insulated masts might be fractured if directly struck by lightning.

Dr. C. C. Garrard: With reference to the question of suppressing the generator fields as quickly as possible, I should like to know whether the author has considered the use of a "suicide" arrangement, as used, for example, on rolling mills, with Ward-Leonard control, to kill the generator field instantaneously. In this connection did the Post Office consider the use of a transverter or the mercury-arc rectifier instead of the high-tension

d.c. machines? The use of the oil circuit-breaker for rupturing the high-tension direct current is interesting, and I should like to know whether it is found necessary periodically to change the oil in this breaker, as I have always understood that direct current carbonizes the oil to a greater extent than does alternating current. What was the diameter of wire used for the aerial? This is of interest from the point of view of corona loss. American whitewood seems to be a very useful kind of timber; has the author had any experience of this for making liquid rheostats? When made of ordinary wood these often suffer from burning due to leakage of current through the wood. It seems to me that American whitewood might be used here. The rise of current on the high-speed breaker seems to be exceptionally large. The normal current is 85 amperes; this rises to 1 400 amperes, which is nearly 17 times full load. High-speed breakers are often used in connection with automatic substations, especially with rotary converters, and the rise of current under these conditions when using high-speed breakers is not nearly so large. What was the time taken for one commutator segment to pass from one brush to the next? I wish to compare this with the time given for the operation of the high-speed breaker, viz. 0·02 sec.

Mr. J. A. Cooper: Why do the Post Office engineers use distilled water for cooling their valves, and why is this cooling water itself cooled by a second water system? Since water is such a bad conductor of heat it would appear that some method of cooling such as spraying would be more efficient, but there is, no doubt, a good reason for the system chosen. The author mentioned, in connection with the valve panels, that if one of the five is not available as a spare when one valve breaks down, it is very easy to locate the faulty valve and replace it. I should like to know what means are adopted for rapidly locating faulty valves. Why is alternating current used for the valve filaments? One might have expected the use of d.c. machines for filament heating as well as for the high-tension supply. One of the amplifying valve units referred to in the paper consisted of a valve having an output of 5 kW; I gather that this valve is not water-cooled. I should like to know why a water-cooled valve was not used; they are generally admitted to be very reliable and should have a long life. One lantern slide showed a very large smoothing condenser. Did the Post Office engineers consider the use of electrolytic condensers in any circuit, and, if so, why did they decide not to use them? In connection with the steel mast stays, it would be interesting to know how the strands are made off to the thimbles. This was not apparent from the lantern slide shown. In connection with the type of aerial shown, I should like to know whether any experiments have been made to discover whether there is any high-frequency loss in the steel wire in the centre of the spreaders and whether, after having had experience of this type of aerial, the Post Office engineers still recommend it as the best type of transmitting aerial.

Mr. T. Plummer: I should be glad of some information in regard to the speed of telegraph signals, and to what extent, if any, distance of reception had an effect on the speed of transmission. In other words, was there any tendency for dots and dashes to run into one another at long distances at high speed? The paper deals entirely with the transmission of signals, and it would be useful to have some information concerning the arrangements of circuits and apparatus which were found to give the best results at the receiving end. Are any weakening effects noticeable due to surface leakage on the various insulators, etc., in wet weather, or is it necessary to compensate for this by an increase of power in the aerial?

Mr. E. H. Shaughnessy (*in reply*): In reply to Mr. Rogers it is not the capacity of the ether for carrying energy that is involved, but congestion is due to the fact that the number of frequencies suitable for long-distance long-wave communications and already utilized is very near to the comparatively limited number available. With regard to lightning, the masts act as lightning conductors and are provided with spark-gaps across the base insulation. The aerial is permanently earthed through the aerial tuning inductance.

With reference to Dr. Garrard's remarks, we have not considered the "suicide" arrangement as the present arrangement is very satisfactory. When it is understood that the short-circuit is straight across the machines the rise of current is not abnormal—with rotary converters in automatic substations any short-circuit usually occurs outside the station. The speed of the machine is 750 r.p.m. and the time taken for a commutator segment to pass from one brush to the next brush is 0·04 second. The chief advantage of whitewood is the low energy loss when placed in a high-frequency electric field—we have no experience with it for making liquid rheostats. The oil in the high-tension d.c. oil switch does carbonize after a number of short-circuits and has to be cleaned, but little or no inconvenience results from this at Rugby.

In reply to Mr. Cooper, distilled water prevents the formation of a deposit on the anodes, and with 54 valves in parallel it offers a higher leakage resistance. Spraying involves a large loss of water due to evaporation. The anode trip-gear and indicating devices are shown in Figs. 13 and 14 and described in the paper, from which it will be seen that the overload relay attached to an individual faulty valve provides a visual indication and trips the control circuit, the tripping of the latter actuating an indicator on the panel containing the faulty valves. The use of alternating current for valve-heating is a more convenient and suitable arrangement where a large number of valves arranged in panels are used. The 5-kW glass valve unit is much cheaper than, and quite as reliable as, a water-cooled valve. Electrolytic condensers were considered, but no commercial type suitable for high-voltage use was available. So far as we have been able to determine, the steel rope does not involve loss; and our experience with this type of aerial shows it to be eminently satisfactory.

Mr. Plummer may take it that distance has no effect upon the shape of the transmitted signal; the prolongation and retardation commonly associated with long land lines are entirely absent. Wet weather has no perceptible effect upon the power required to give the required aerial current.